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Modeling the Data Systems Role of the Scientist (For the NEEDS Command and Control Task)

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Modeling the Data Systems Role of the Scientist

(for the NEEDS Command and Control Task)

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I. EXECUTIVE SUMMARY

The purpose of this study effort is as follows:

> To expand the scope of the NASA End-to-End Data System (NEEDS) modeling effort to include a description of the scientists' functions in the data system.
>
> To design a model of the scientists' command and control activities.
>
> To develop a plan leading to validation of the model as part of the NEEDS command and control activity.

In accomplishing the study, research was conducted into the command and control activities of the scientists for five space missions. The selected missions provided a representative spectrum of command and control systems employed by NASA for recent missions. The missions reviewed were

> International Ultraviolet Explorer (IUE)
> Solar Maximum Mission (SMM)
> International Sun-Earth Explorer (ISEE 1,2,3)
> High-Energy Astronomy Observatory 1 (HEAO 1)
> Atmospheric Explorer 5 (AE-E)

The information gained by this review provided a basis for developing a generalized description of the scientists' activities. The description was found to be well represented by a sequence of activities. Because of this characteristic, it was decided that a series of flowcharts would be used to convey this information. This set of flowcharts constitutes a model of the scientists' activities within the total data system. The model, which is presented in this paper, has been developed through three levels of detail. The first is general and provides a conceptual framework for discussing the system. The second identifies major functions and should provide a fundamental understanding of the scientists' command and control activities. The third level expands the major functions into a more detailed description.

For purposes of this study effort, the data system has been organized into three major subsystems (figure 1, following page 29) with conceptual boundaries between them. The relationships (influences) among the subsystems are identified at the boundaries as conditions associated with the flow or movement of information and data products across the boundaries (data flows). Further refinements of the model are planned, leading to its implementation on a computer and validation as part of the command and control task. Future efforts include the following:

(a) Developing a mathematical model. This effort will determine the appropriate parameters associated with functional elements and the movement of information and data products. The effort will develop both mathematical and statistical relationships which serve to relate the parameters.

(b) Installing and demonstrating the model on an appropriate computer. This effort will involve selecting an appropriate software package, and implementing and testing this package on the computer to ensure correct and effective operation.

(c) Integrating the operational model with the remaining activities in the command and control task.

(d) Participating in the validation of the command and control model.

A successful Scientific User Modeled Subsystem for Command and Control (SUMS) could make significant contributions in several areas of program management. During a new mission definition phase, the use of the model could provide the information needed to assess resource requirements and system configuration. The model could assist in analyzing the impact of major data system changes on the scientific user. In addition, SUMS could be used to

obtain daily workload projections for the autonomous scheduling system, a major activity of the command and control task.

II. INTRODUCTION

NASA's End-To-End Data System (NEEDS) effort is intended to provide a basis for transition into future flight projects by identifying and developing new technologies. This process is to be conducted in an orderly fashion, with systems research and analysis as one basis for prioritizing the various efforts.

A. Objective

The first objective of this effort is to expand the scope of the ongoing NEEDS Command and Control (C & C) modeling effort to include a description of the scientists' functions in the data system. The ongoing command and control study effort and the Resource Effective Data System (REDS) modeling activity for the end-to-end data system are integral parts of the NASA data system analysis activity.

The second objective is to design a model for the scientists' command and control activities. An understanding of the REDS model, as implemented on a computer, was obtained prior to commencing this activity so that maximum benefit from the ongoing work could be obtained.

The last objective is to develop a plan leading to validation of the model as part of the NEEDS command and control activity.

The justification for modeling data systems arises from the realization that NASA'S budget is not likely to increase along with the technological ability to telemeter increased numbers of bits. When a future space project is conceived, an analysis of science objectives, the cost of data processing, delivery, storage, and data analysis ought to be performed. Data system models are the tools of choice for this purpose.

B. Approach

The approach taken to achieve the objectives was to

1. Study a selection of recent missions focusing on the scientists' command and control functions. Five near-Earth missions were selected. These missions are representative of NASA's experience in active command and control operations. They are as follows:

   International Ultraviolet Explorer (IUE)
   Solar Maximum Mission (SMM)
   International Sun-Earth Explorer (ISEE 1, 2, 3)
   High-Energy Astronomy Observatory 1 (HEAO 1)
   Atmospheric Explorer 5 (AE-E)

   The results of the study of the designated missions are contained in a companion report, "Information Base Used to Formulate the Scientific User Modeled Subsystem for Command and Control (SUMS)."

2. Organize the gathered information in order to separate the scientists' command and control activities.

3. Evaluate the activities in order to assess the feasibility of including these functions in a data systems model.

4. Develop a model concept which can adequately describe the functions experienced by the five missions studied.

5. Extend the model to accommodate an incompletely specified data system, which can easily incorporate changes as the data system design progresses.

6. Present potential applications of the Command and Control System model. Included are applications to new flight projects, to automatic scheduling systems, and to major configurations of the data system.

C. NEEDS Overview

This overview is included for those readers with limited exposure to the NEEDS Program. NASA's End-to-End Data System (NEEDS) program is intended to identify, develop, and make available for its future ventures the critical technologies and analysis tools which otherwise would not be accessible. A total data systems approach is taken, so that a proper cost-benefit assessment of each element of the system can be made. To this end, NEEDS-sponsored research is aimed not only at components which show potential for future

applications, but also at analytical tools which can aid in the system's assessment.

The NEEDS program has been structured into three phases. These phases and their objectives follow:

<u>Phase 1</u>. Develop and demonstrate critical data system components which will provide cost-effective solutions for several near-term, high data rate processing problems.

Support systems analysis and planning for subsequent program phases.

<u>Phase 2</u>. Develop new systems concepts and identify and develop technologies which will enable significant improvement in information system performance and cost.

Design, develop, and demonstrate advanced data subsystem technologies and techniques which when integrated into end-to-end systems will enable near real-time data management.

<u>Phase 3</u>. Develop a mission capability for reliable handling and preprocessing of future space-acquired data (includes data storage, high-speed computer systems, and the capability for onboard fault tolerances).

Provide a reduction in data access time and facilitate access to multiple data bases for multisource research by developing the architecture, protocols, and executive software for ground-based, high-rate, multiple-source data base management systems.

Improve the performance of the command and control process while reducing labor-intensive costs by developing automated command generation capabilities and modeling and demonstrating command capability.

Develop a system capability for cost-effective data system design and implementation (including standard interfaces and protocols) and data analysis and develop system configuration options for the post 1990's.

The Phase 1 program element for GSFC emphasis is the Resource Effective Data System (REDS). The GSFC objectives in regard to this element are to survey existing data handling systems and requirements, compile future mission and user requirements, develop system models, and test the effectiveness and efficiency of the system as new technology and techniques are introduced.

Phase 2 activities are grouped in the program elements listed below. Some areas of development do not directly involve GSFC. The objectives for each element are included. Actions in these areas are still in progress with most activity scheduled for completion in FY 82.

Management/Systems Analysis

Provide management direction and coordination for entire program.

Analyze program element technical performance.

Develop total system concepts.

Provide liaison with information systems design activities.

Information Adaptive System

Develop and demonstrate a capability for adaptive control and processing of sensor data for onboard spacecraft application.

Ancillary Data and Support Computing

Develop concepts and ground demonstration hardware for providing onboard ancillary data (time, orbit, attitude) and associated ground validation and maintenance support.

Modular Data Transport

Develop and demonstrate concept and subsystems which will utilize a modular approach for data transport through the entire data system and a distributed architecture for spacecraft processing.

Command and Control

Define command and control system concepts which will reduce command response time and distribute control to the user community.

Data Base Management

Develop data base management techniques which facilitate rapid, use-oriented interaction with large volume data bases.

Develop an optical mass memory system design which provides large on-line storage capacity with high data transfer rates.

Massively Parallel Processor

Develop and demonstrate a high-throughput computer capable of processing high-rate imagery data in real time.

The final structuring of the Phase 3 efforts is still being determined. The structure of the effort and identification of developmental tasks is expected to be finalized by the end of FY 81.

D. Command and Control Overview

This overview is included for those readers with limited exposure to the NEEDS program. Command and Control is identified within the NEEDS concept as one of the functional elements which compose the planned (generalized) NEEDS data system. Its description in NEEDS concept documentation is as follows:

> Command and Control (Ground). The ground command and control element provides the user a facility to process command requests. User command requests can be composed of command types such as real-time commands, group commands, stored commands (commands stored within the onboard command and control element for delayed execution), and onboard command and control element program changes. User requests are received by the ground command and control element via the mission planning element.
>
> Command requests received by the ground command and control are immediately processed for real-time command requests or stored within a data base for group command requests and stored command requests for later execution. Command processing consists of command validation, command formatting, error coding, packet generation, and finally transmission and verification. Command conflict resolutions will be a function of the sequence design and integration process which prepares command sequences for transmissions. A file containing the command history is maintained by the ground command and control.

This description includes many of the functions performed in what may be currently identified as the Payload Operations Control Center (POCC) and the Command Management Facility (CMF), if applicable to a specific mission. A discussion of the functions of the POCC and the CMF is given in Appendix B entitled Mission Support System.

In addition, command and control includes functions associated with the experimenters' facilities. In a general sense this facility supports the users' (principal investigators and teams, guest observers, etc.) requirements for interaction with satellite and supporting data. Through analysis of downlinked information, the scientist ascertains the need to change (command)

the status of instrumentation in space.

The examination of the scientist's command and control function/activities, described in this report will include the NEEDS concept functions identified as User and Data Bases (User) and those elements of Command and Control (Ground) appropriate to the scientist (user). These functions are as follows:

User. The user of the data performs information reduction/extraction operations on the received data. Data may be requested by the user via data queries. The user may operate the onboard sensor via the mission planning element and monitor its status. In general, the end-to-end nature of the system couples the user tightly to the sensor.

Data Bases (User). In general, these data bases are under control of the user, who schedules accesses and performs his own data base management.

Experimenter Facility. The experimenter facility is the location where the user operates, receives and manages his data, performs any desired analysis and develops his command requests/requirements to be placed on the data system. This facility may be centralized or distributed.

III. THE SCIENTIFIC USER SUBSYSTEM

A. General

The Scientific User Modeled Subsystem for Command and Control (SUMS) is to be a tool which can be useful for planning future satellite flight projects in addition to assisting in scheduling of telemetry acquisition. The design is such that questions of increasing complexity can be addressed, system optimizations done, and alternate configurations assessed. The greater the level of detail required, the greater the effort and resources required to use the model.

The work reported here concentrates on functions associated with the scientific effort. Analysis of the spacecraft and ground data systems is progressing through other concurrent efforts under NEEDS Command and Control sponsorship.

The command and control data system can be thought of as comprised of three major interrelated subsystems: the scientific user subsystem, the mission support subsystem, and the spacecraft/experiment platform subsystem as illustrated in figure 1. Concepts associated with the spacecraft platform and the mission support systems are contained in appendices A and B. The scientific user subsystem is the major subject of this study.

In developing the model, two sets of elements were chosen to model the functions performed by the scientist and his supporting team and equipment. (1) The transformation set is comprised of elements with inputs, outputs, and algorithms which represent, to the chosen level of detail, the processes carried out within that portion of the data system. (2) The transportation set is comprised of elements which account for movement of information between

transformation elements, including delays and possible loss. The user model consists of these collections of elements and, in addition, a data flow management system.

The functions performed by the scientist user system are presented at three levels of detail. The third level, most detailed level included herein is not specific enough to contain the detailed hardware characteristics used in the researcher's work. While description to this level is possible, and for certain applications useful, developing the model to that level of detail is a logical extension of the concepts to be discussed, and it would be unnecessarily repetitious for the purpose of this report. The three levels to be discussed are sufficiently generalized to accommodate the five mission types included in this report. Consequently, when implemented on a computer, studies for optimization could be conducted for IUE, SMM, ISEE, AE, or HEAO 1 types of satellite missions. The results could influence TDRSS and NASCOM loading, command and control procedures, spacecraft design, IPD loading, and the scientists' computational analysis capacity for future missions. Model extensions could be implemented to embrace additional future mission types.

B. Model Application

In the early phases of a data system design, little specific information about the project is known. However, NASA experience is relevant to new missions. The experience gained from some similar missions will permit the establishment of "rules of thumb." The combination of experience and specific choices for a future mission can be used for the model calculation. As the system design progresses, the rules can be replaced by the emerging design relations and design parameter values. The model, in other words, can become a special kind of archive for the experience gained through NASA's involvement in flight projects. Unlike conventional archives, application of the model

results in a computerized automatic invocation of this accumulated knowledge. In order to place into perspective the role which SUMS could play in mission design and operations, the total NASA End-to-End command and control modeling activities will be reviewed. The NEEDS effort consists of study activities which analyze the mission support and science user subsystems. A future effort is planned which would integrate these new technologies into an operational data system for both mission design and automatic telemetry acquisition scheduling. The NEEDS command and control decomposition is described as consisting of three major subsystems which can be treated separately.* A fully operational SUMS can play a key part in the model-assisted design of a future mission. In addition, once a mission concept is accepted, and the science investigations have been identified through the normal announcement and proposal process, SUMS could be used independently to assist the scientists in ground support and analysis systems design. This assistance could include projections of the requirement for shift operations at the users' facilities, and calculations of reserve system capacity requirements in order to achieve stated mission performance goals. For the operational mission, SUMS could be used to assess the impact of proposals for changes in telemetry acquisition and ground support services

*However, the science objectives for a mission will influence the experiment platform alternatives. The available telemetry capacity within the mission support system will influence the telemetry rate choice alternatives. The projected budget situation will influence the degree to which a project can be an ambitious undertaking. And the resources anticipated for scientific analysis should determine the volume of data to be telemetered. NASA has been criticized for telemetering more data than it could afford to analyze. In the past, where exploratory missions were the rule and onboard selection and processing capacity was limited, this situation may have been justified. Because of the successful demonstrations offered by missions like SMM, preselection and preprocessing should now be considered by every project to control the volume of telemetered data. The cost of configuring a platform for onboard processing must be balanced against the cost of transmitting, storing, reducing, and analyzing the telemetered bits.

on the scientific user subsystem. These assessments could be helpful for both day-to-day and emergency situations.

C. Introduction to Detail Levels

The Level 0 model (figure 1), the most generalized description of the system, is useful in defining and developing the concepts fundamental to the study effort, the basic idea of the boundary conditions (interrelationships) between the science effort and the remainder of the NASA data system, the interrelationships in a flowchart context, and the generalized boundary conditions of interest to this study effort.

The Level 0 model groups the functions and activities of the command and control/data system into three categories:

Scientific User includes the experimenters, their facilities, and the functions, activities and processing which occur under their control.

Spacecraft/Experiment Platform includes all functions and activities performed on board the spacecraft.

Mission Support System includes all ground-based functions and processing activities not specifically included in the science category.

The data and operational requirements and other functional interrelationships that each category places on the other two are the boundary conditions of major interest in this study.

At detail level 1, the model represents the major functions within the level 0 superstructure. This organizational framework provides a good intermediate level overview of the system operation and associated data and information flows. At level 1, each of the three level 0 categories (subsystems) is separately partitioned into major functional elements. At level 0, the entire data system is characterized as gross functional elements with generalized input and output parameters (boundary conditions) and transfer characteristics between the inputs and outputs. When a portion of

the system (one or more elements) is to be described in more detail, logically a level 0 element is replaced with a sequence of functions (elements) which more completely represent the transformation of input to output parameters in the format of a flowchart. Each of these level 1 elements has input and output parameters (boundary conditions) and transfer characteristics (algorithms) for processing input to output. Similarly, description of a portion of the system to level 2 amounts to replacing level 1 elements with more detailed sequences of elements. Each level 2 element has input and output parameters, and appropriate transformation functions. It is not necessary to define the entire data system to detail level 2 (or higher) in order to use portions of the model system at that detail level. The consequences are that details associated with the less completely specified portions are summarized at the more general level appropriate for the particular analysis being conducted. Such summarization would not reduce the validity of the analysis.

D. The Basic Model

The Level 0 model organizes the NASA data system functions into three subsystems. These three categories are the spacecraft/experiment platform for all functions performed in space, the scientist user for command and control functions associated with obtaining data and the processing/analysis of the received data, and the mission support system for all ground-based functions not being performed in the scientist user category. These elements are illustrated in figure 1 (foldout at page 31). While these choices have consequences in terms of the perspective or focus of this effort, they are not unique; and alternate categories would serve as well for overall data systems design.

Spacecraft/Experiment Platform, Level 0. In the development of this model, no commitment to specific spacecraft design alternative is implied although mission specific functional requirements and/or performance specifications are addressed. Functions like the following are included:

> Measurement of scientific events to include the operation of the sensors and experiment instruments. The activities within this function will vary significantly from one mission to the next in such areas as type of events measured/data generated, the flexibility of the experiment system and the timely control and adjustment of experiment activity.
>
> Command handling to receive commands from the ground; distribute, either with or without temporary storage, to the appropriate functional process onboard the spacecraft; and to perform any control function for which programmed.
>
> Data handling to receive scientific information/data from the measuring sensor/instrument, temporary storage of data pending transmission to the ground; data processing within established capabilities and formatting of data into packets as required.
>
> Telemetry to transmit information/data to the ground.

Mission Support System, Level 0. The mission support system, for the purposes of this discussion, is assumed to contain all the ground-based functional activities not included in SUMS. No commitment to design system alternatives is implied although some functional requirements and/or performance criteria are included. Included within the mission support system model are functions like the following:

> Ground communications necessary to transport data among the functional elements. This includes the STDN, NASCOM, the network scheduling and operation and any other communications necessary to tie the data system together and provide the means for the required data flow.
>
> Systems management activities to ensure proper operation of the project. This includes the appropriate project operations control center, command management/processing, and supporting ancillary functions.
>
> Data processing and handling activities necessary to receive data, handle the data, perform any required processing before the data/information is provided to the scientist user. This includes both quick-look and production data preparation for the "decom tapes" or "experimenter tapes" from IPD.

Scientific User, Level 0. Included in this model are all resources associated with the experimenters' data processing, reduction, analysis, command and control, and scientific research. (One cannot treat the command and control system as separate from the research analysis system because the two are so tightly interdependent.)

Functions like the following are included in this model:

Developing the commands desired and required to get the satellite-borne scientific instrument to gather the scientific data. This includes any necessary planning, scheduling, prioritization, consulting, and conflict resolution done by the science team.

Responding to requests from functional elements within the mission support system for information, and/or interactions necessary for successful project operation and completion.

Receiving, processing, and analyzing the scientific data initially acquired by the satellite instrument and processed/handled by the mission support system. This includes quick-look data, if appropriate, for feedback into the generation of commands for instrument operation as well as production data for final scientific analysis and use.

Preparing reports.

Preparing archival forms of the science data.

Within the command and control system, the scientific user subsystem is the least quantifiable, and consequently the most difficult and controversial of the systems to analyze. Yet it is for the resulting science output that new scientific satellite missions are flown.

E. <u>The First Expansion, Level 1</u>

In the level 1 model, the level 0 categories of functions are replaced with a greater level of detail. This controlled expansion represents major functional categories. Only the development of the Scientific User subsystem will be treated in this part of the paper. The level 1 discussion of the spacecraft/experiment platform and the mission support system are contained in appendices A and B.

Included in this level 1 system description for the scientist user model are the following major elements:

Reception, Control and Distribution
Analysis for Decisionmaking
Planning and Coordinating Activities
Decisionmaking
Command Preparation and Forwarding
Analysis of Production Data
Development of Scientific Knowledge

The interrelationships among these elements are shown in figure 2 (foldout as page 33). Discussion of transportation elements, shown as lines in the figure, is deferred to the "Interrelationship" discussion in section 4.

<u>Reception, Control and Distribution</u>. This function, as a separate element within the scientist area, is not always apparent. There are, however, a number of what might be considered routine administrative functions necessary to ensure efficient operations. This element accounts for the capability to receive incoming material, identify what it is and who it is for, control the distribution process and distribute the material to its intended receivers. If the incoming material is electronic data, the element would account for the necessary switching capability to a computer or an image reception device, as appropriate.

<u>Analysis for Decisionmaking</u>. This element accounts for analysis which leads to or supports the command and control decisions. Command and control related

analysis typically shares resources with science data reduction and analysis. Consequently, it is inevitable that coupling among these elements will occur. Also accounted for in this element would be any accompanying data storage. The incoming data, for this element, referred to as quick-look data, is processed as appropriate for the mission. The processed data is evaluated for necessary completeness, and any additional data/information required is requested or otherwise obtained. The primary output is the results of the analysis which are furnished to the level 1 decisionmaking and planning/coordination elements.

Planning and Coordinating Activities. This element accounts for coordinating activities, meetings with other experimenters, and/or interactions with other organizations. Also included are provision for planning activities related to future endeavors. The results or outputs, in addition to the expected coordinated responses and programs, include revised plans and outgoing requests for information or actions by others.

Decisionmaking. Committees of scientists use the results from analysis, coordination, and many other inputs to decide how to next configure/adjust an instrument or group of instruments. The decisionmaking element accounts for internal coordination and conflict resolution among the committees. The output from this element consists of decisions for subsequent spacecraft or experiment configuration, operation, and control.

Command Preparation and Forwarding. This element accounts for processing of command and control decisions. The amount of processing varies by mission and tends to complement elements within the mission support system. Decisions are converted to the necessary instrument commands or command requests. The commands or command requests may be tested and coded before being formatted for transmission or forwarding to the operations control center or other

network elements. Necessary documentation is also maintained in this element.

Analysis of Production Data. This element accounts for the computer reduction and analysis of the input processed production data received from the Information Processing Division (IPD) or its equivalent. The data may be received as magnetic tape, images or other forms appropriate to the unique mission. Any additional information found to be required for complete analysis is obtained. Some of the results of this analysis may be fed back into decisionmaking. The time frame associated with these processes is generally quite long, often as long as 2 years but sometimes as short as a few days. Reduced and analyzed data are also forwarded for archived storage.

Development of Scientific Knowledge. This element represents the culmination of the mission program. It accounts for resources consumed in investigations. Outputs include scientific papers, published documents, and presentations.

F. The Second Expansion, Level 2

At level 2, the model represents each of the level 1 elements in greater detail. Each level 1 function in the scientist user area is expanded to identify activities or subelements. This level 2 functional structure provides a foundation for comparing the command and control systems among various missions at a moderate level of detail. It also provides an organizational framework for structuring data flows throughout the system.

Reception, Control and Distribution. This element is modeled as five separate activities or subelements.

Identification. In this element, an examination is made of incoming data or material to determine the material type, the procedure for handling and the process for distribution within the system.

Electronic Reception. This element accounts for the electronic capability to handle incoming digital transmitted data, directing it either to an appropriate computer or other processing device.

Facsimile Reception. This element accounts for the ability to record (receive) facsimile transmissions.

Distribution. This element ensures that products, whether data or otherwise, are forwarded to the proper destination within the system.

Storage. This element accounts for the retention of data and information volumes.

The interrelationship of these activities is shown in figure 3 (foldout at page 35).

Analysis for Decisionmaking. The subelements for this activity are as follows:

Data Processing. This element accounts for the computer-supported processing of the data products.

Storage. This element accounts for the capability to retain data and information volumes.

Information Evaluation. This element accounts for validation steps preliminary to analysis to ensure that all required data and information is present. If not, action is initiated to obtain requisite information or data.

Information Analysis. This element accounts for the examination, compilation and/or extraction of meaningful scientific information from the data and supporting information.

The coupling of these elements is illustrated in figure 4 (foldout at page 37).

Planning and Coordinating Activities. Included subelements are

Coordination Requirements. This element accounts for the identification of situations and requirements that need coordination with othermission support personnel or other scientific users; it includes requests for actions, obtaining and processing the results.

Meeting Preparation. This element accounts for the preparation and information gathering necessary before a coordination type meeting.

Coordination Meetings. This element accounts for face-to-face discussion and teleconferencing for coordination activities. These meetings may have a significant impact on the current and future decisionmaking and planning processes.

Plans Development and Update. This element accounts for the process of accepting the results of coordination activities, formulating new plans, merging results with other plans and developing revised plans. The time required for completion of activities within the element varies significantly and will frequently be of sufficient length as to be a major delaying factor in identifying and implementing new (and improved) ideas, concepts and procedures.

The coupling of these elements is illustrated in figure 5 (foldout at page 39).

Decisionmaking. The model subelements for this function follow:

Information Examination. This element accounts for the examination of information which leads to the decision process. This element is similar to, and an extension of the normal analysis process. It provides for the review and comprehension of analysis results and other pertinent information so that command and control requirements may be generated.

Decision Development. This element is the point in the system where decisions for command and control requests are developed. In addition,

requirements and recommendations are brought together to influence the decisions appropriate for a specific mission and/or experiment.

Internal Coordination. This element accounts for the sharing of objectives and schedules among the various experimenters participating in the planning process. All interested science personnel (or committees) are given an opportunity to contribute.

Conflict Resolution. This element accounts for management decisions which resolve any remaining conflicts pertaining to command and control after the committee process is concluded.

The coupling of these elements is illustrated in figure 6 (foldout at page 41).

Command Preparation and Forwarding. This element includes the following subelements:

Command Development and Preparation. This element accounts for converting the command and control decisions/requests from a qualitative type set of decisions into a format appropriate for command coding either by the scientific user or mission support personnel.

Command Coding. This element accounts for coding the command requirements into a format and language for testing by computers (and the instrument control mechanisms). Coded commands are quality controlled to ensure accuracy.

Command Verification and Testing. This element accounts for verification and testing of the coded commands as required by the mission's data system. This testing process, if used, is normally mission unique and may involve a spacecraft simulation package on a computer.

Storage. This element accounts for the retention of data and information volumes. In this instance, a log of commands is among the information stored.

Command Transmission. This element accounts for the active process of sending commands and command requests through the proper media (mail, computer link, phone call, etc.) to the mission support system.

The coupling of these functions is illustrated in figure 7 (foldout at page 43).

Analysis of Production Data. The following subelements are included:

Data Processing. This element accounts for reduction and analysis using a computer or other suitable alternative.

Storage. This element accounts for the retention of data and information volumes. It includes services such as are available through, but not necessarily provided by, NSSDC.

Information Evaluation. This element accounts for the preliminary analysis to ensure that data is usable and sufficiently complete to meet a particular study need. Insufficiencies are resolved through acquisition action.

The coupling of these elements is illustrated in figure 8 (foldout at page 45).

Development of Scientific Knowledge. This element is comprised of the following subelement and is illustrated in figure 9 (foldout at page 47):

Information Analysis. This element accounts for the thought, literature searching, and other analysis processes associated with the development of scientific knowledge. Included within the scope of this element are computer-assisted work and reading processes. Not included are production or batch data processing (included in the previous element).

Information Integration. This element accounts for the merging of supporting or contradicting science information.

Scientific Reporting. This element accounts for the formulation of theories and the writing of reports. Included are the publication and distribution of scientific work in the form of oral seminars, literature, internal reports, etc. Also included are functions like refereeing journal articles.

New Proposal Preparation. This element accounts for preparation and submission of proposals for future research. Proposals can be for future flight experiments, for investigations with existing hardware (as with IUE), and for studies with data in national archives, etc. Also accounted for within this element are peer group committee activities, etc.

A large fraction of the scientists' current and future resources ought to be committed to analysis, writing papers, speaking, and writing proposals for future work. Shifting more of the burden for future command and control activities to the scientists must be considered in balance with these activities. The objective of this "Development of Scientific Knowledge" expansion is to provide a basis in order to account for (1) the command and control burden on total science resources, and (2) the adequacy of science resources to analyze telemetered data. Further expansion would be necessary to account for details associated with knowledge generation.

IV. INTERRELATIONSHIPS AND BOUNDARY CONDITIONS

A. General

In this section, techniques for accommodating various levels of detail within the model and for substituting higher levels of detail for specific functional elements are to be discussed. For purposes of presentation, the discussion will treat the interrelationships between the scientific user model and the mission support system model. This focus will not only serve to illustrate these concepts, but to provide a point of reference for planning purposes to those involved in the mission support system model development.

B. Technique for Accommodating Detail Levels

The example in figure 10 (foldout at page 49) serves to illustrate the level 0 model, but with emphasis placed upon the interfaces among the model transformation elements. The four categories of both information and data which are exchanged between the scientific user and the mission support system are identified within the region labeled boundary 1 in the figure. These categories represent the functional transportation elements of the level 0 model for boundary 1. The corresponding category between the mission support system and the spacecraft/experiment platform subsystem is identified at boundary 2 in the figure.

In figure 11 (foldout at page 51), the level 1 representation of the scientific user subsystem which was shown in figure 2 has replaced the SUMS level 0 block in the previous figure. (Also, only a portion of the level 0 mission support system is shown.) As illustrated in this flowchart, commands and command requests resulting from operations in the "command preparation and forwarding" element are passed through the "command communications" transportation element. Arrival of commands in the network is accommodated by a forwarding process, indicated by the arrow, and a feedback process,

labeled "A" in the figure. (The forwarding and feedback functions are modeled by algorithms.) The information is fed back to SUMS through the "Coordination Communications" transportation element for distribution to the appropriate transformation elements within this subsystem.

A completely defined set of transportation elements for the boundary between SUMS and the network depicts all communications between the subsystems. Developing a schedule for a mission is the equivalent of defining the total network load across a boundary for a mission. Thus, the link between different subsystem models is expected to occur through the development of appropriate schedules.

In this example, the network was treated at level 0, and SUMS was treated at level 1. Data and information transferred back into the level 1 subsystem were depicted within the lower level element through the use of algorithms. An appropriate algorithm was used for each communications path between the subsystems. (Similarly within SUMS, algorithms are used to represent the communications paths between inputs and outputs of the transformation elements.)

C. Technique for Substituting Levels of Detail

In the example discussed in part B above, the model represented to level 0 was redefined to include a portion at level 1. Two adjustments were made. First, a higher order element was replaced by a more detailed representation. Contained within this level 1 representation, is a more complete specification of the information and data which pass across the shared boundary. The second adjustment is made to the level 0 portion in order to accommodate this increased detail. Algorithms need to be supplied which account for feedback, transfer, and other processes that have direct bearing upon the more detailed portion of the model. Substitutions and

adjustments need to be made for each step in the evolutionary process of model development. However, this procedure is expected to become a matter of routine.

V. PERFORMING A CALCULATION WITH SUMS

The flowcharts given in this report are one representation of the subsystem model. To use SUMS, significant effort in the form of model refinement, implementation on a computer, and testing must occur. Model refinement will consist of selecting from the infinite number of possibilities an appropriate set of input and output parameters for the elements, then developing algorithms which relate the parameters. The algorithms will reflect the experience gleaned from this study's review of five missions. Implementation on a computer can commence when the model refinements are complete. Testing of the model will first show that SUMS represents current missions, followed by applications to future missions. Finally, the operational SUMS will be integrated with the other subsystem models to form a system model for command and control.

It is premature to discuss the details of the elements, parameters, and algorithms. Nevertheless, it is possible to discuss calculations using SUMS. This is because the flowchart nature of the model composed of elements imposes constraints on the analytical techniques available for solution. Elements have the following characteristics:

(1) input parameter values
(2) output parameter values
(3) parameters which are neither input nor output, but are used in algorithms for the element
(4) algorithms which relate parameters within the element
(5) statistical variations accommodated in algorithms

Consequently, SUMS will have a complex mathematical structure. Input parameters to one element are outputs from another. It is possible that some of these expressions may be transcendental in nature. Because of this structure, and the need to be able to substitute for selected portions of the

system, an iterative solution for the desired parameters is the most likely choice.

Such a calculation typically commences with an initialization step and proceeds by employing strategy to force a convergent solution. If the calculation is for a specific epoch (t) then a set of values

$$\{V\}$$

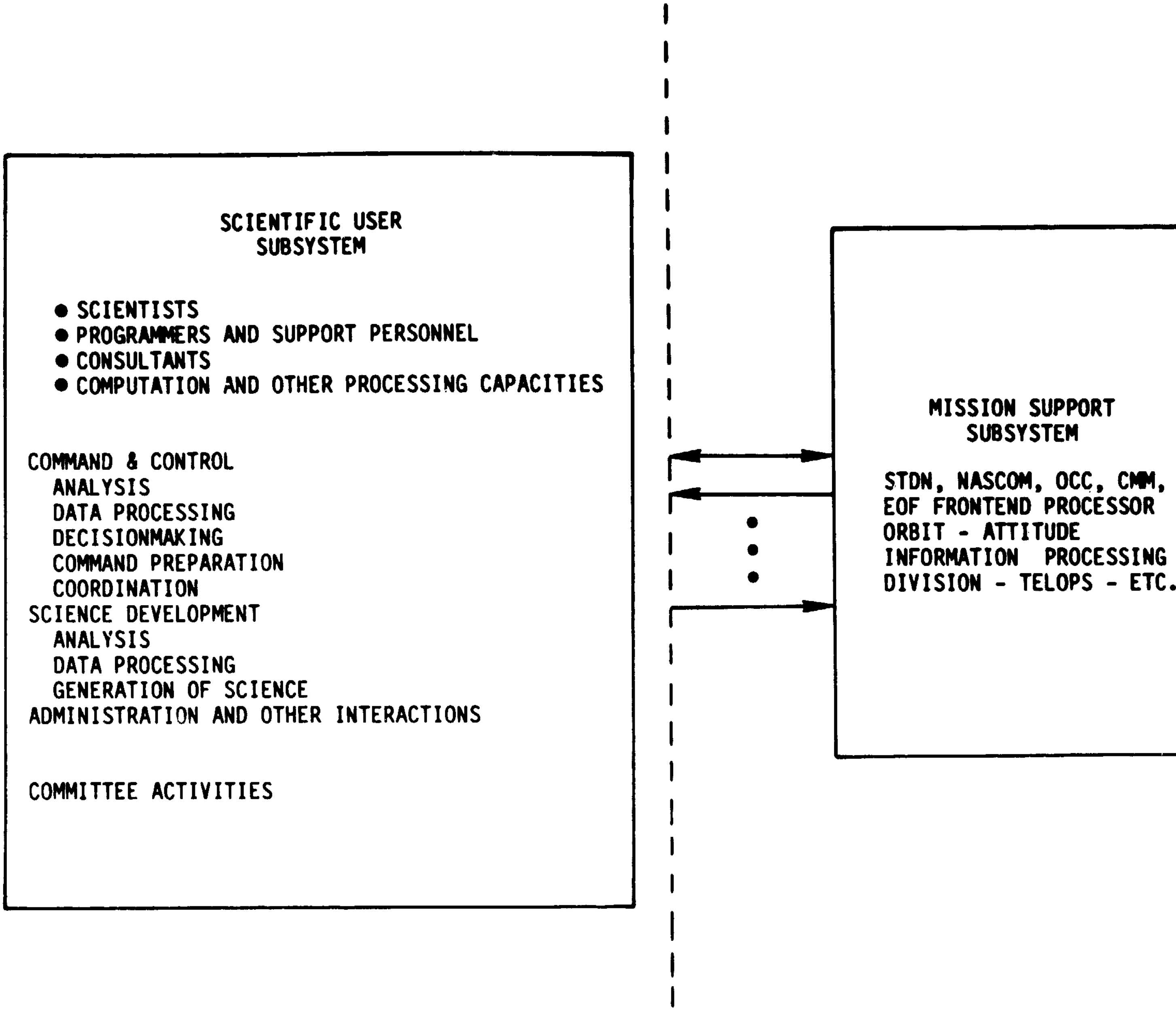
will be determined. If the calculation is a simulation, then the result is a set of distribution functions for parameters

$$\{f(V,t)\}$$

(No predisposition for the functional representations $\{f(V)\}$, is implied. On the contrary, the resulting distribution functions are expected to be diagnostics for system design.)

A simulation will probably be treated as a sequence of epoch calculations, where time is accounted for in a consistent way in all elements of the system. However, the precise formulation will result from the model refinement and implementation steps.

A simulation provides a technique for testing both the sensitivity of the model data system to failures anticipated during nominal operations, and the sensitivity of the system to controlled changes in parameters. Simulations are, however, computationally expensive to run. Consequently, both simulations and epoch calculations have potential value for design and scheduling problems to be treated by SUMS.


SCIENTIFIC USER
SUBSYSTEM
● SCIENTISTS
● PROGRAMMERS AND SUPPORT PERSONNEL
● CONSULTANTS
● COMPUTATION AND OTHER PROCESSING CAPACITIES
COMMAND & CONTROL
ANALYSIS
DATA PROCESSING
DECISIONMAKING
COMMAND PREPARATION
COORDINATION
SCIENCE DEVELOPMENT
ANALYSIS
DATA PROCESSING
GENERATION OF SCIENCE
ADMINISTRATION AND OTHER INTERACTIONS
COMMITTEE ACTIVITIES
MISSION SUPPORT
SUBSYSTEM
STDN, NASCOM, OCC, CMM,
EOF FRONTEND PROCESSOR
ORBIT - ATTITUDE
INFORMATION PROCESSING
DIVISION - TELOPS - ETC.

Figure

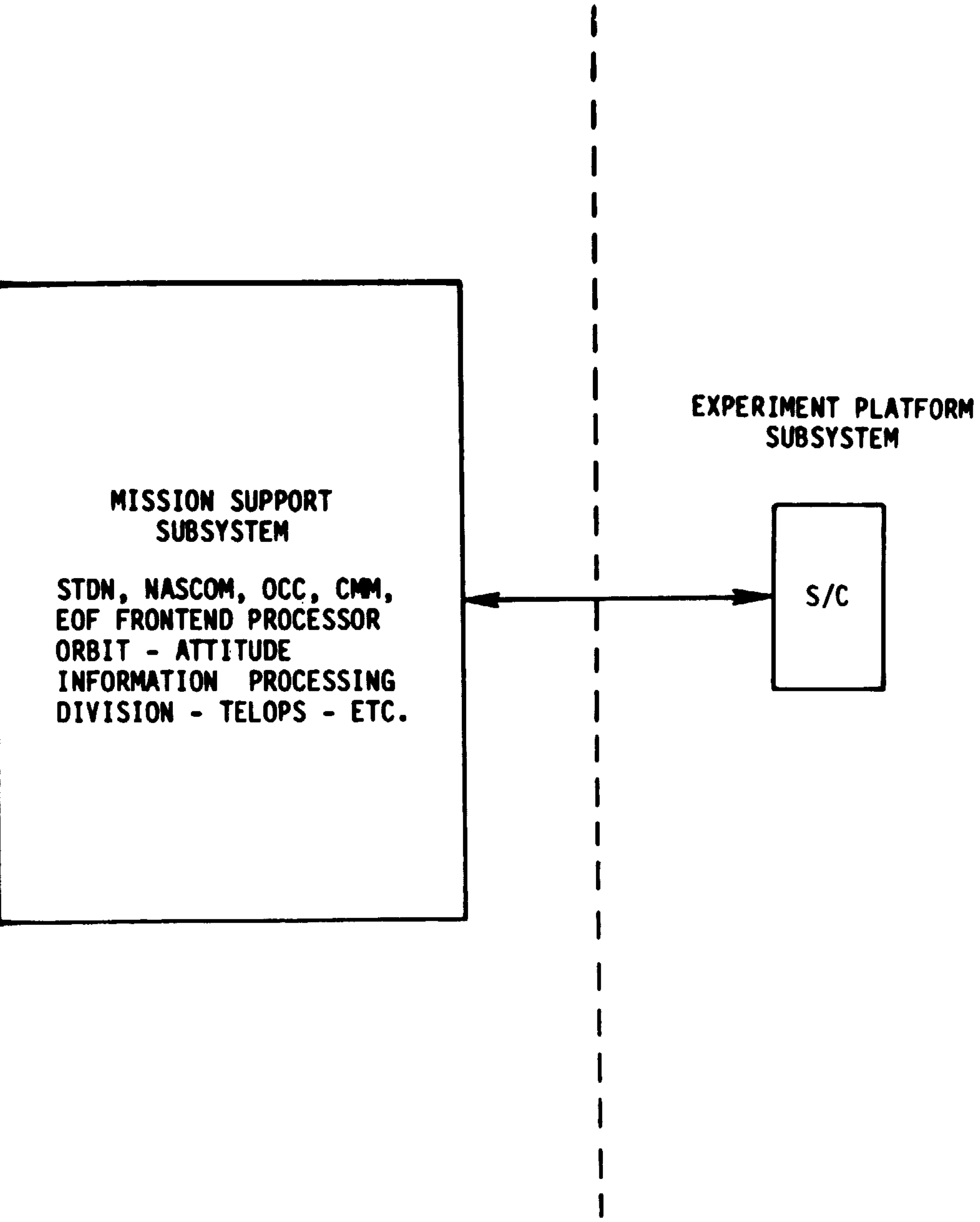


Figure 1. The Basic Model (Level 0)

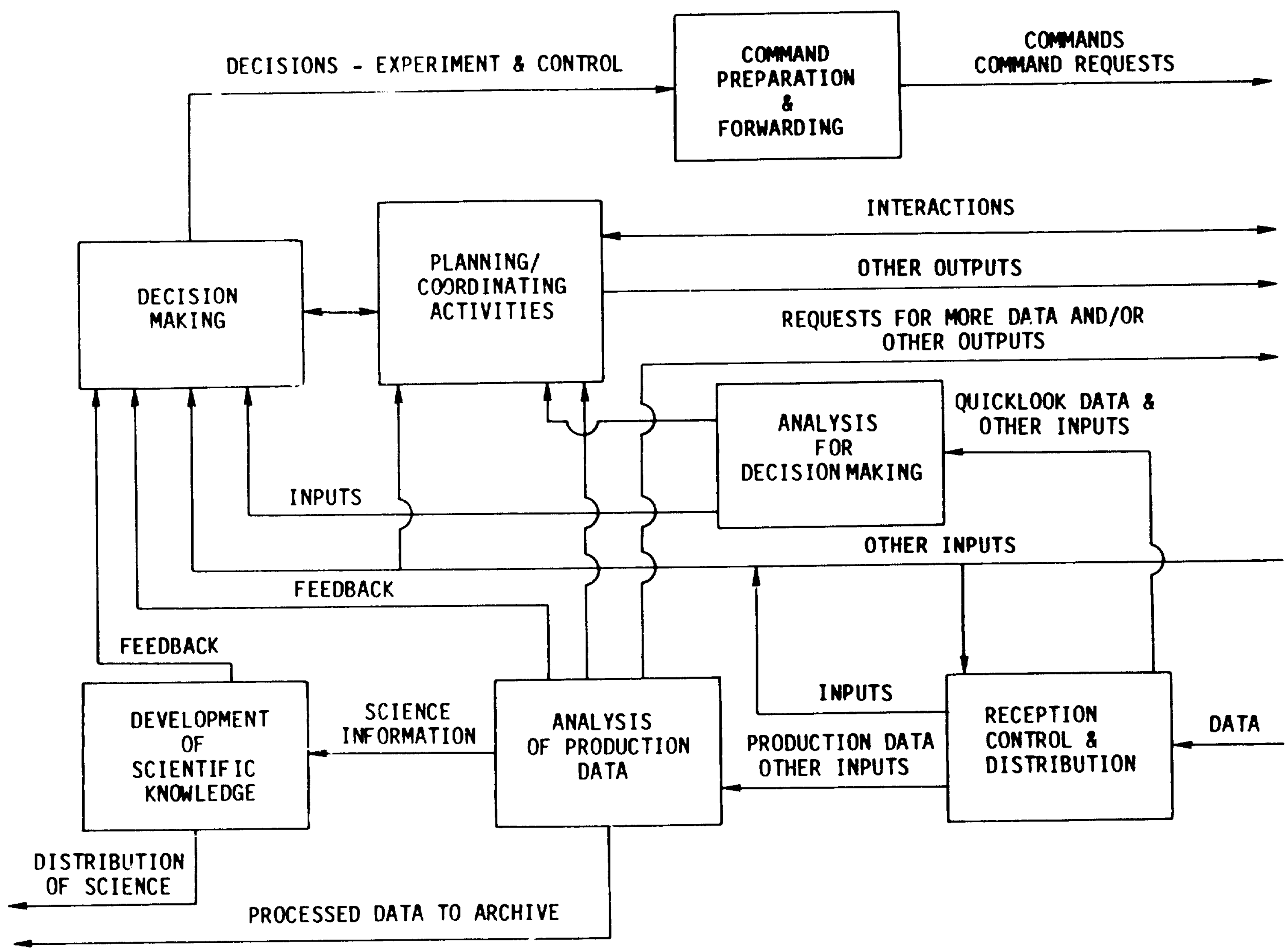


Figure 2. Scientific User Model (SUMS Level 1)

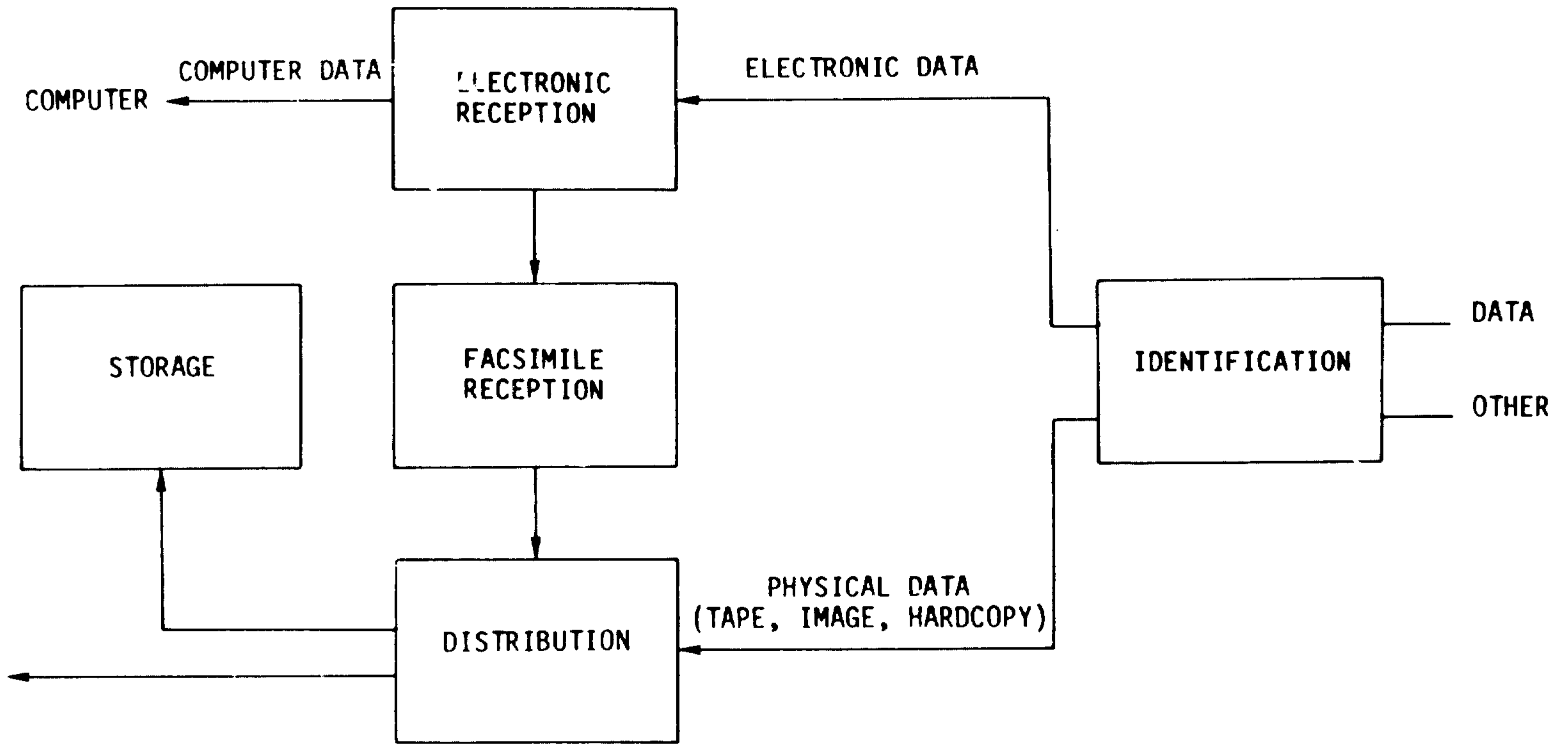


Figure 3. Reception, Control and Distribution (SUMS Level 2)

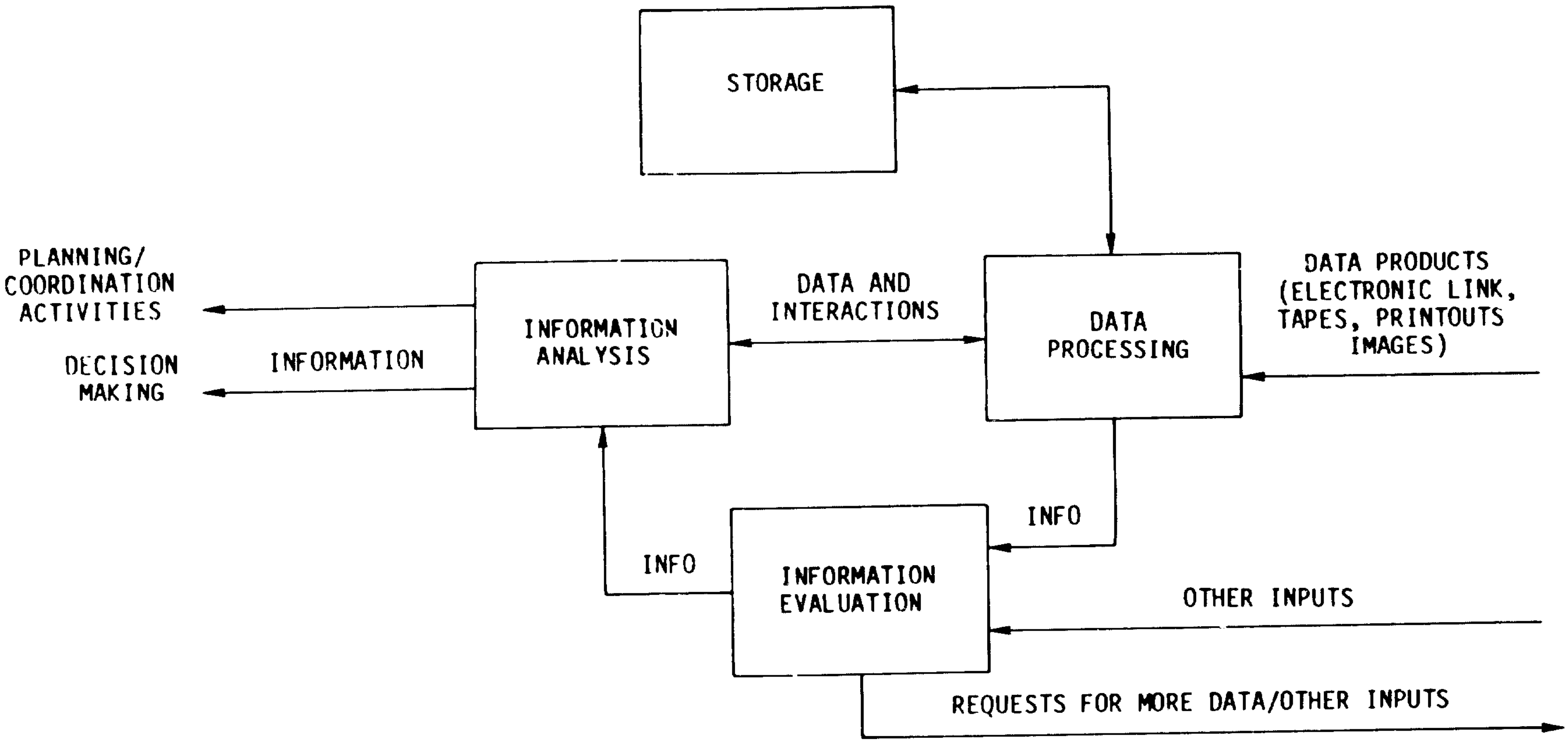


Figure 4. Analysis for Decisionmaking (SUMS Level 2)

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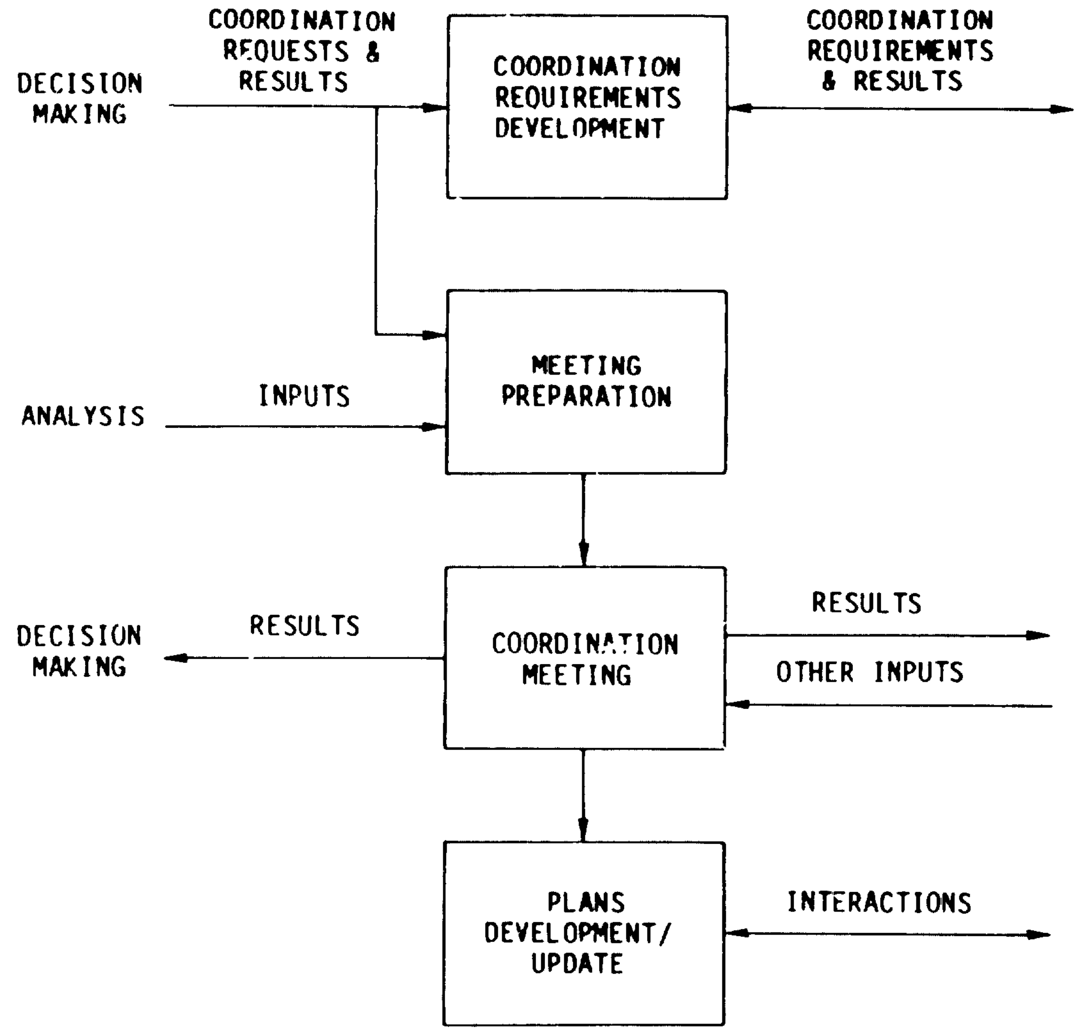

Figure 5. Planning and Coordinating Activities (SUMS Level 2)

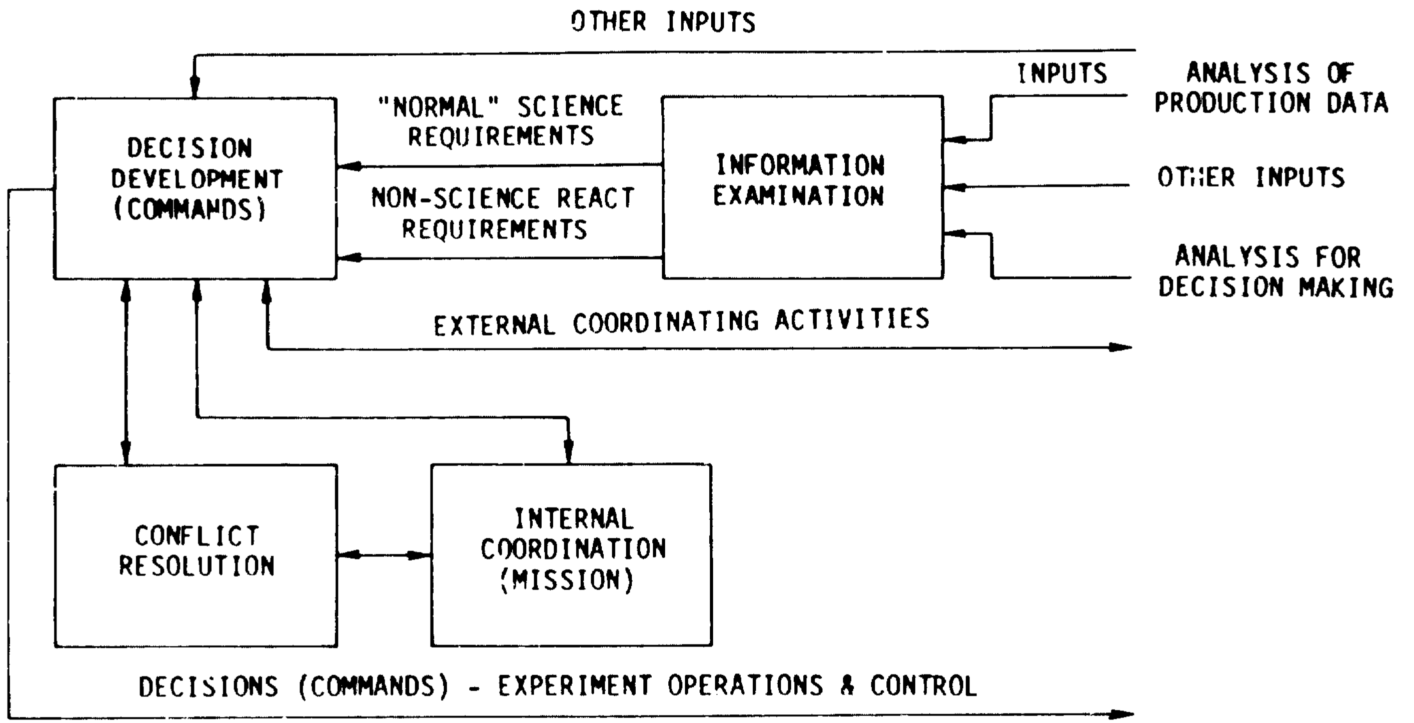

Figure 6. Decisionmaking (SUMS Level 2)

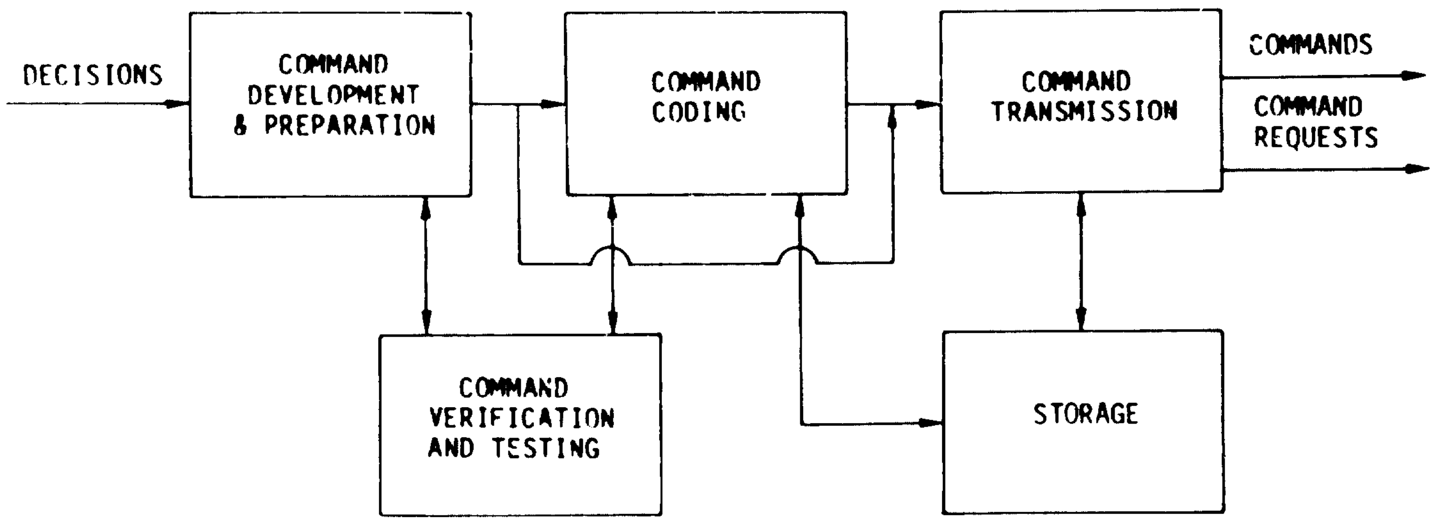

Figure 7. Command Preparation and Forwarding (SUMS Level 2)

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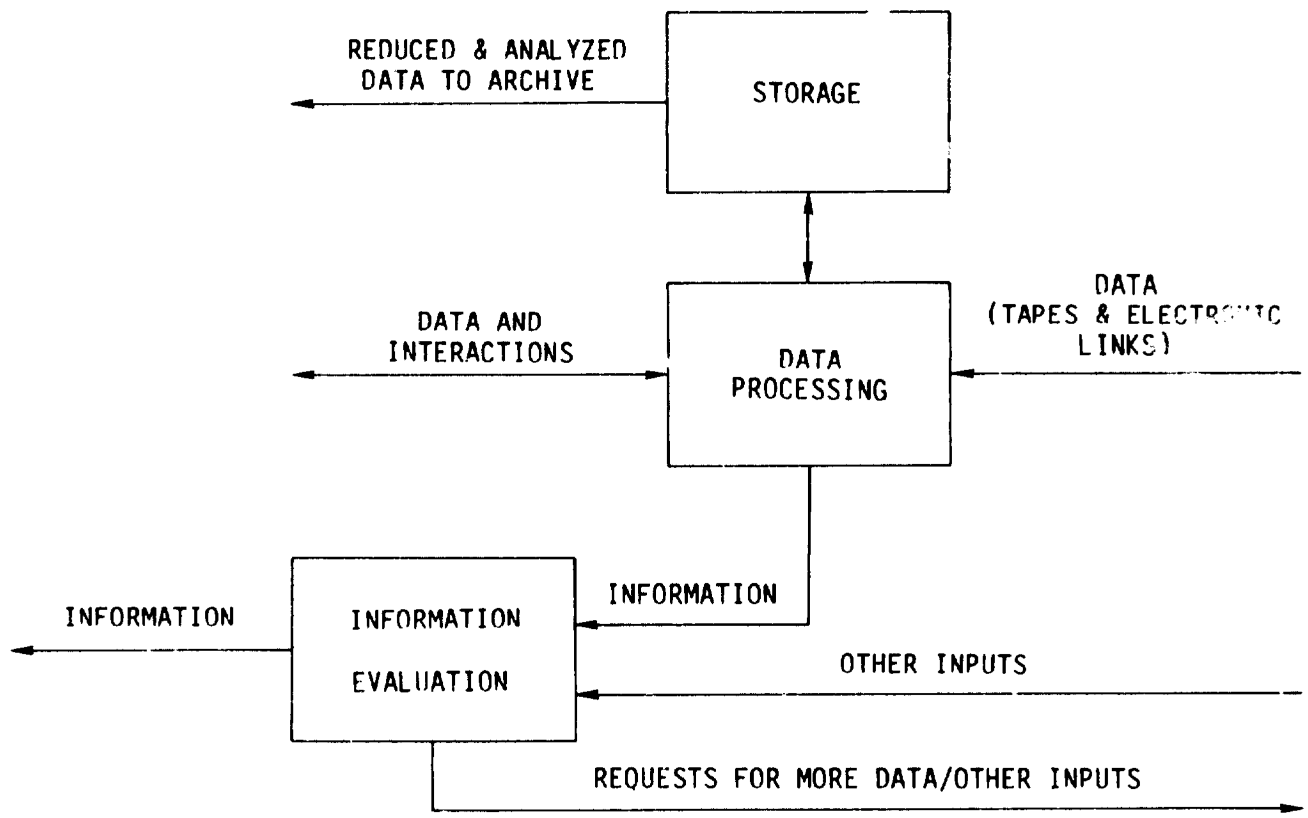

Figure 8. Analysis of Production Data (SUMS Level 2)

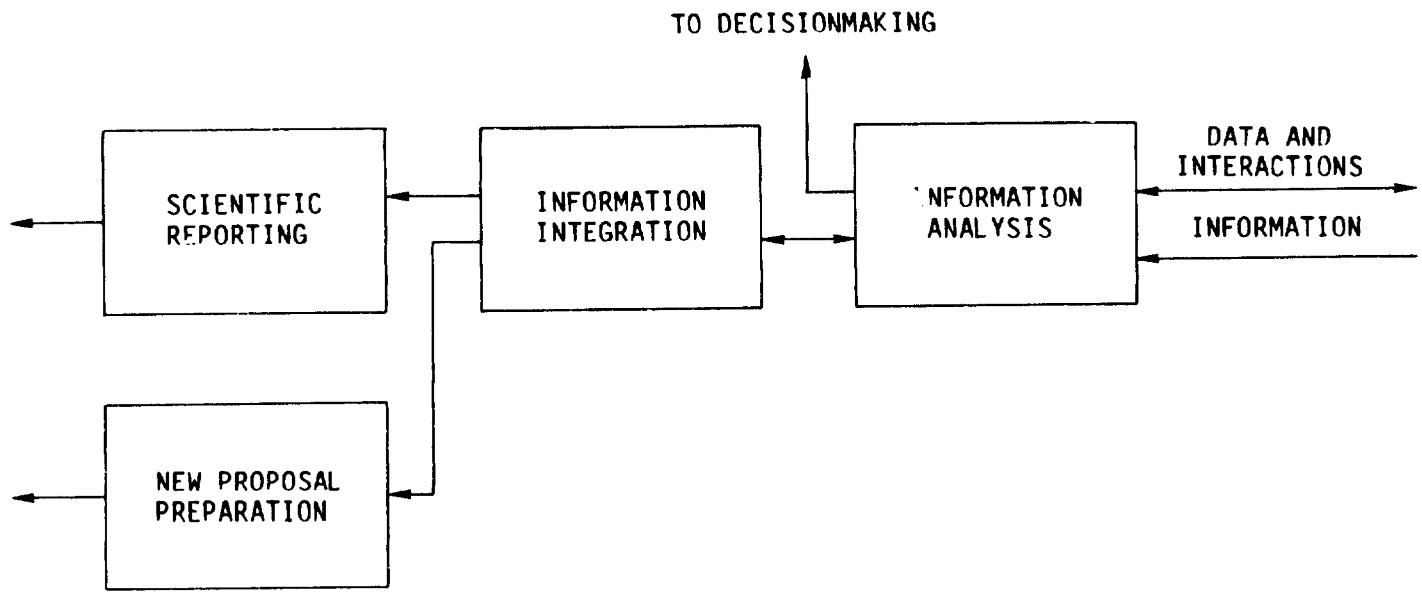

Figure 9. Development of Scientific Knowledge (SUMS Level 2)

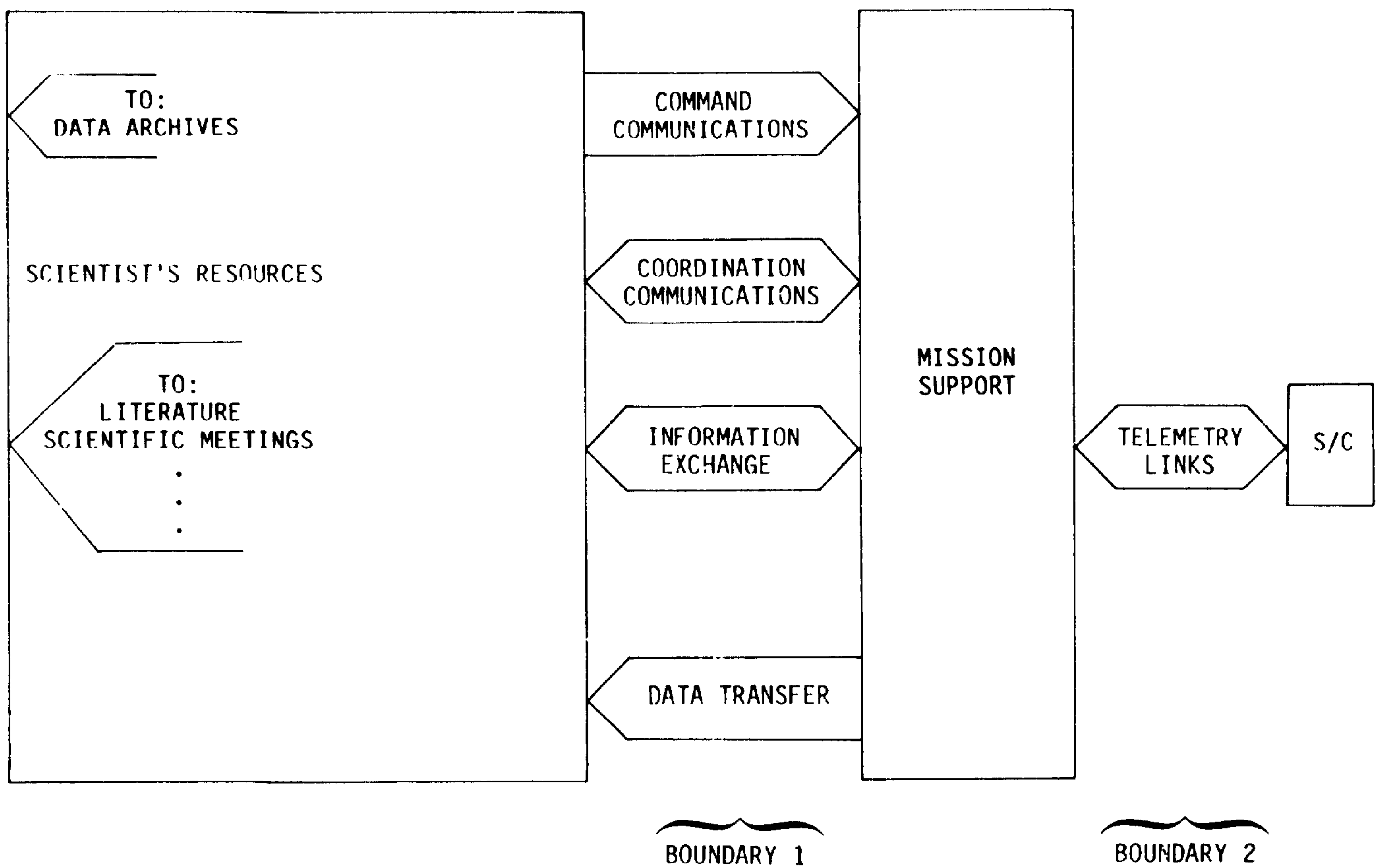

Figure 10. Boundary Illustration (Level 0)

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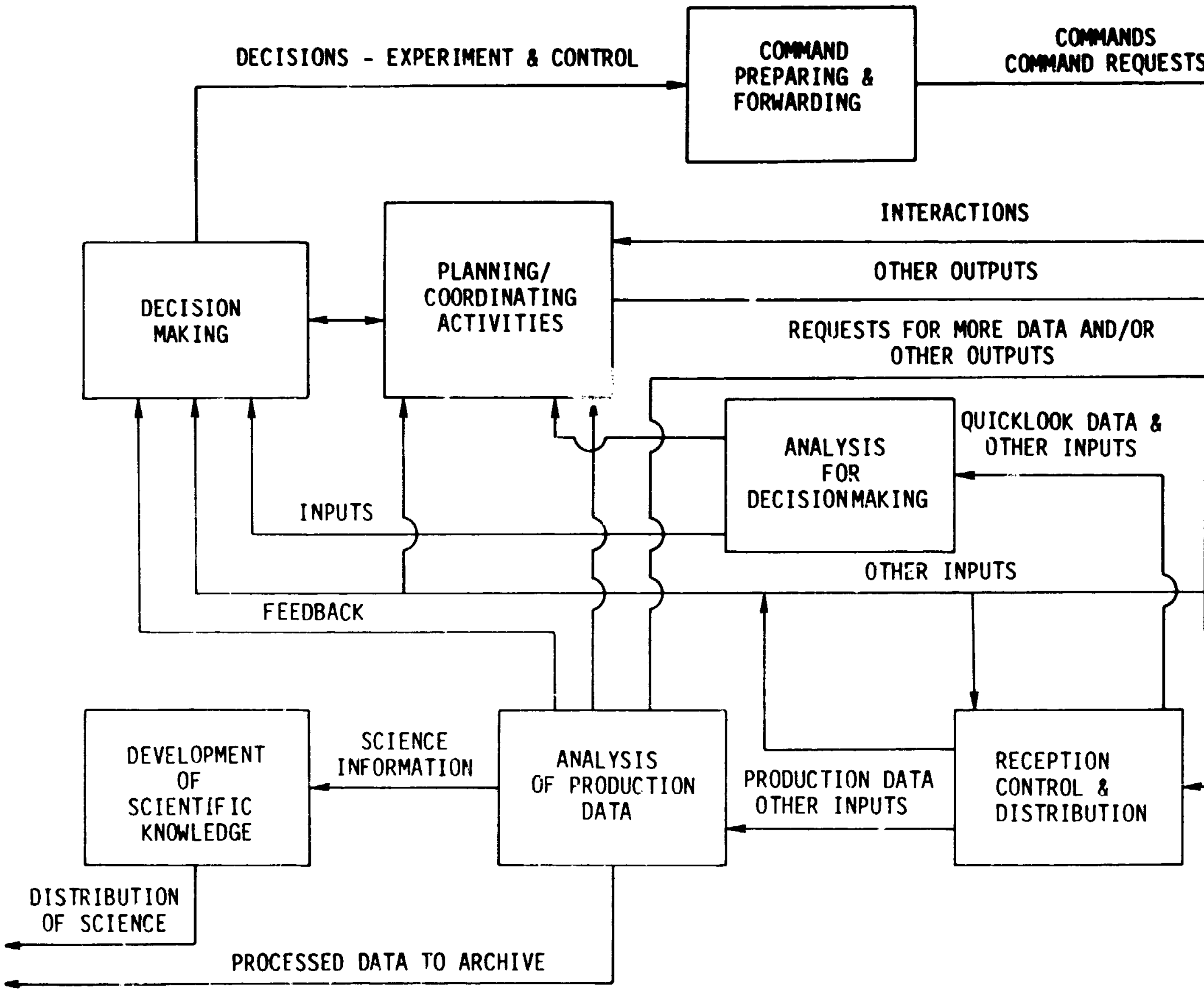

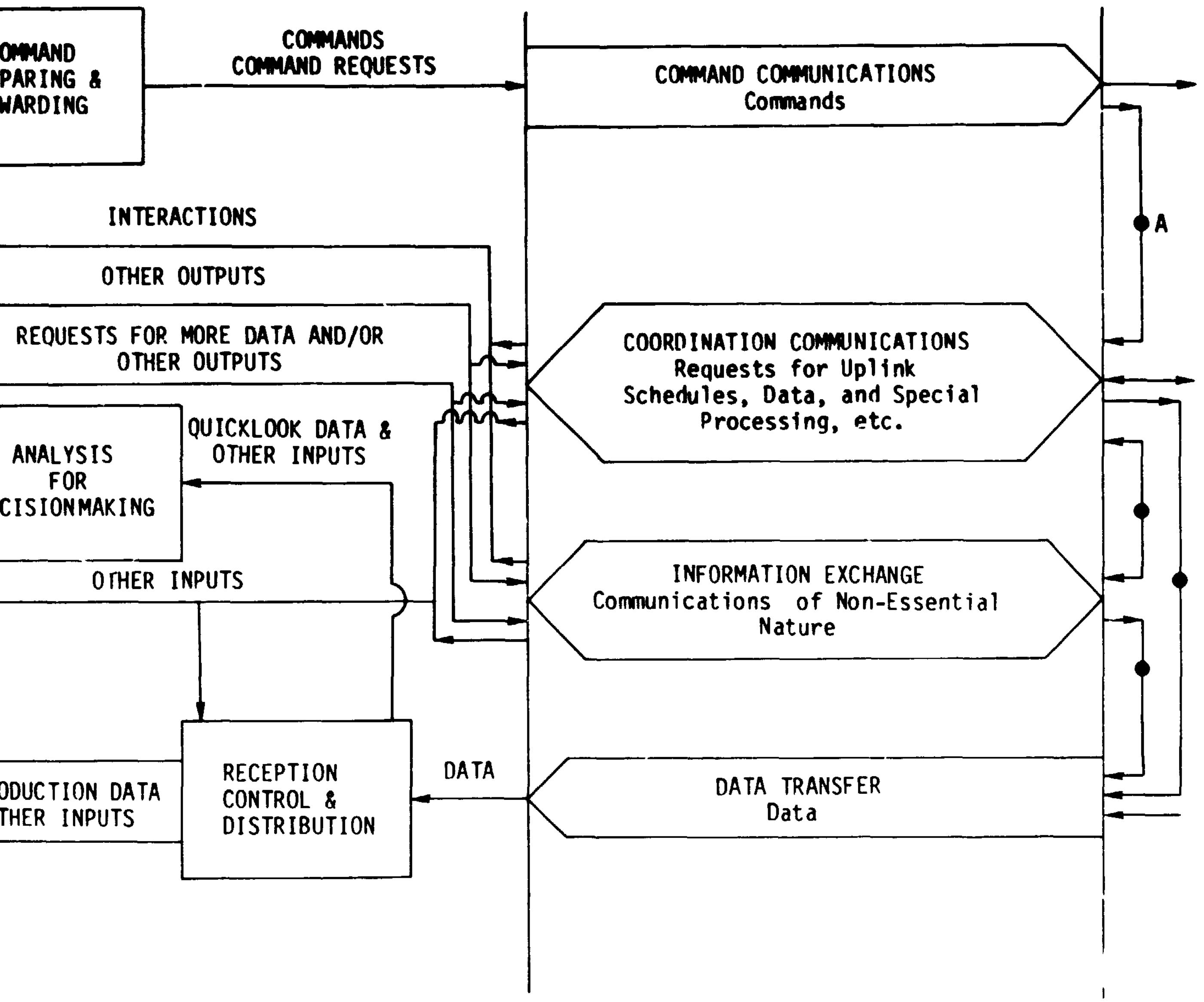

Figure 11. Boundary Channels (Level 1)

APPENDIX A

SPACECRAFT/EXPERIMENT PLATFORM

Data sensing, data handling, and onboard processing, command and control of the spacecraft, data storing operations, preparation of telemetry, and communication services are accounted for within the spacecraft/experiment platform portion of the data system.

Most missions have three operational phases:

Launch--the activities from lift-off until the end of powered flight in a preliminary Earth orbit.

Acquisition--orbit and attitude maneuvers, spacecraft checkout, and experiment activation. Once powered flight has ended and the spacecraft has separated from the launch vehicle, the acquisition phase of maneuvers and testing begins.

Mission Operations--carrying out the normal activities for which the flight was intended, namely providing information about events as directed by the users.

The launch phase is the most well-defined, and is normally carried out and controlled primarily by personnel concerned with the rocket launch vehicle and not involved with subsequent mission operations. The major impact which the launch phase imposes upon the performance of the NASA End-to-End Data System arises from the size and weight constraints resulting from the launch vehicle's capabilities. It has been expensive to launch sophisticated data processing equipment into space. Consequently, spacecraft have tended to be passive. Extensive computational and data handling support was required on the ground, not only to analyze the data, but to select the appropriate data for analysis. Recently solid-state technology has tremendously decreased the weight of data processing equipment. Also in the future, the Space Shuttle's increased payload capacity will allow the use of hardware that is heavier and

more sophisticated than that which was previously used. For these reasons, the computational services provided on the spacecraft platform are expected to increase.

Once the proper orbit or trajectory and attitude have been obtained, and the spacecraft and experiment hardware have been activated and tested, the mission operations phase--in which the spacecraft carries out its basic purpose--is initiated. Spacecraft control and user data handling/processing becomes (or should become) a routine process. The spacecraft performance discussion to follow is in the context of the mission operations phase.

Size, weight, proven microcomputer technology, stand-alone ancillary data requirements, and the exploratory nature of the experiments are competing factors which limit the capability of the spacecraft to do more extensive onboard processing of experimental data. Major increases in onboard computational capacity will alter the spacecraft's capability to reduce the time and costs associated with ground-based computing support. The reduction is expected to occur from pre-selection of the data for analysis prior to telemetry.

The major spacecraft platform elements are listed below. An onboard computer (data processor), if present, is considered as an integral capability. The major functions are

<u>Command Handling</u>. Commands are received and validated by the command handling element. They can be executed in real time or stored and routed for execution at specified times. This service is normally provided by command decoders and relay units. Sophisticated stored command programs and/or onboard computers, if used, will participate in this process.

<u>Experiment Data Sensing, Handling and Processing</u>. This element covers the sensing of information concerning the desired events as directed by user command. Sensor data is acquired, digitized, stored,

conditioned, validated, handled, and processed, and then transmitted to the ground via telemetry.

Orbit System. This element covers onboard orbit control activation (normally by ground command) and the generation of tracking signals for later orbit determination on the ground. Future types of navigation measurements will allow autonomous navigation to be performed onboard for computation and maintenance of precision position and velocity.

Attitude System. The attitude control and determination systems provide the capabilities to maintain stability and pointing control, to sense attitude information, and to provide attitude-related data.

Communications, Electrical, and Thermal Control. This element provides spacecraft housekeeping services. Communications control directs the receipt of commands and transmission of telemetry, as well as internal data distribution. Electrical control provides spacecraft power generation, storage, and distribution between subsystem modules. Thermal control provides warming or cooling (along with appropriate monitoring capabilities) to maintain spacecraft components within acceptable temperature limits.

Spacecraft Clock. This element provides time signals to other functions. This clock is normally a regularly incrementing counter. In the future, an accurate GMT (or other similar absolute time) may be provided onboard using an autonomous spacecraft clock.

Telemetry Data Handling. This element covers telemetry commutation (i.e., the process of sequentially sampled data sources in a repetitive manner), encoding (the creation of the telemetry bit stream), storage, and transmission. The future concept of data packetization may modify these procedures significantly.

The model data flow is illustrated in figure A-1. Commands are received from the Spaceflight Tracking and Data Network (STDN). Commands may be executed or stored for later access. Depending upon the tracking system type for a specific mission, a procedure is followed which results in orbit determination.

Commands routed to the Experiment Data Sensing, Handling and Processing element enable the collection of information and detection of events as needed by the experiments. Experiment data is accumulated by the telemetry data handling element for transmission to the ground. The attitude system; orbit

system; communications, electrical, and thermal control; and spacecraft clock functions are similarly directed by ground command. Appropriate monitoring data is then accumulated by the telemetry data handling element for later processing on the ground.

The relationship of the spacecraft/experiment platform to the total system depends upon the data rates and the volume of telemetry from the satellite, and on the tradeoff between data processing onboard the spacecraft versus what must be later done on the ground. Other factors include the quality and reliability of the onboard hardware, and the characteristics of the spacecraft's orbit.

The spacecraft/experiment platform functional activities (and any supporting computers) perform the following data services:

Command Handling. This element receives all commands from the STDN, stores the commands (if appropriate), and sends commands to appropriate elements for execution (figure A-2). It includes the following:

> Receipt and Validation. This subelement receives commands from the ground and compares them to allowable commands for validation. Primary verification is normally achieved by ground analysis of command memory dumps transmitted via telemetry back to the ground.
>
> Command Storage. This subelement stores commands that are not to be executed immediately. Stored commands are released for execution at a later time based on time computation or various sensor states.
>
> Decoding and Routing. This subelement decodes and routes commands.

Experiment Data Sensing, Handling and Processing. This element performs the primary scientific data gathering effort using unique scientific instruments (figure A-3). It includes:

> Sensor/Instrument. This subelement monitors, registers and/or gathers the raw scientific data and converts analog values into digital values.

Computer Control. This subelement, if used, accounts for the internal functioning of an experiment unique onboard computer/processor. Using either stored command sequences and incoming commands, it manages the scientific data gathering effort.

Instrument Control. This subelement ensures that the various parts of the instrument are set/positioned in accordance with commands.

Data Processing. This subelement, if an experiment unique computer is used, performs data editing, analysis and evaluation and, if the computer is so programmed, provides feedback to computer control for the conduct of experiments based upon some analysis of sensor data. The microprocessor can provide the capability to verify and select data. Also, experiment data packetization and compression is possible.

Tape Recorder. This subelement accounts for recording of data for later handling and inclusion into telemetry.

Orbit System. This element (figure A-4) provides the following services:

Sensing. This subelement generates a tracking signal for later ground orbit determination. The type of orbit tracking system will vary by missions.

Control. This subelement maneuvers the platform based on ground command.

Attitude System. This element (figure A-5) provides the following services:

Attitude Sensing. This subelement senses the relationship of the spacecraft to the orientation of a reference vector (i.e., Earth's magnetic field or unit vector in direction of the Sun, a star or the center of the Earth).

Attitude Determination. This subelement accounts for the calculation of the orientation relative to the inertial reference frame.

Attitude Control Computation. This subelement generates appropriate control hardware commands to respond to computed requirements for reorie ng the spacecraft.

Control Hardware Activation. This subelement activates attitude control hardware to change the spacecraft's orientation in response to health, power, stability, or other requirements.

Communications, Electrical and Thermal Control. This element provides the following housekeeping functions:

> Communications. This subelement accounts for communications equipment and the system which transmits data from one location to another onboard the spacecraft and from the spacecraft to the ground.
>
> Electrical. This subelement includes the electrical system for energy generation and power control to spacecraft subsystems, instruments, and payload.
>
> Thermal. This subelement includes the equipment and system to monitor heating, cooling, and thermal control and to maintain all spacecraft components within acceptable limits.

Spacecraft Clock. This element produces timing signals to drive onboard data acquisition, processing, and data transmission. The timing signal (number of time intervals) is furnished as input to other elements. Commands may be received which result in adjustments in the time computation mechanism.

Telemetry Data Handling. This element (figure A-6) includes the following:

> Telemetry Commutation. This subelement samples the various instrument and spacecraft systems for data.
>
> Telemetry Storage. This subelement uses a tape recorder or other medium to store/collect telemetry data until the data can be transmitted to the ground.
>
> Transmission. This subelement sends data from the spacecraft to the ground station.

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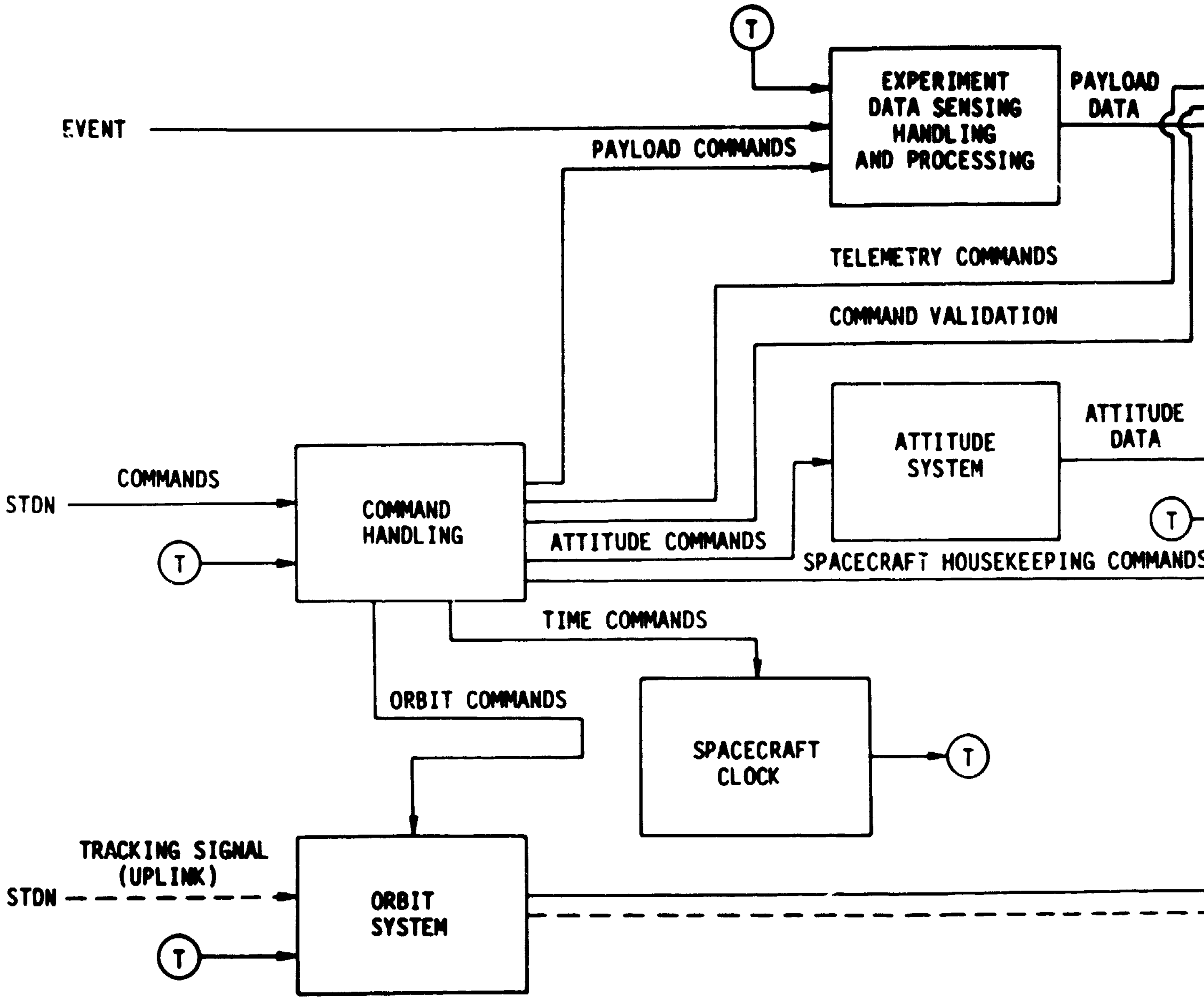

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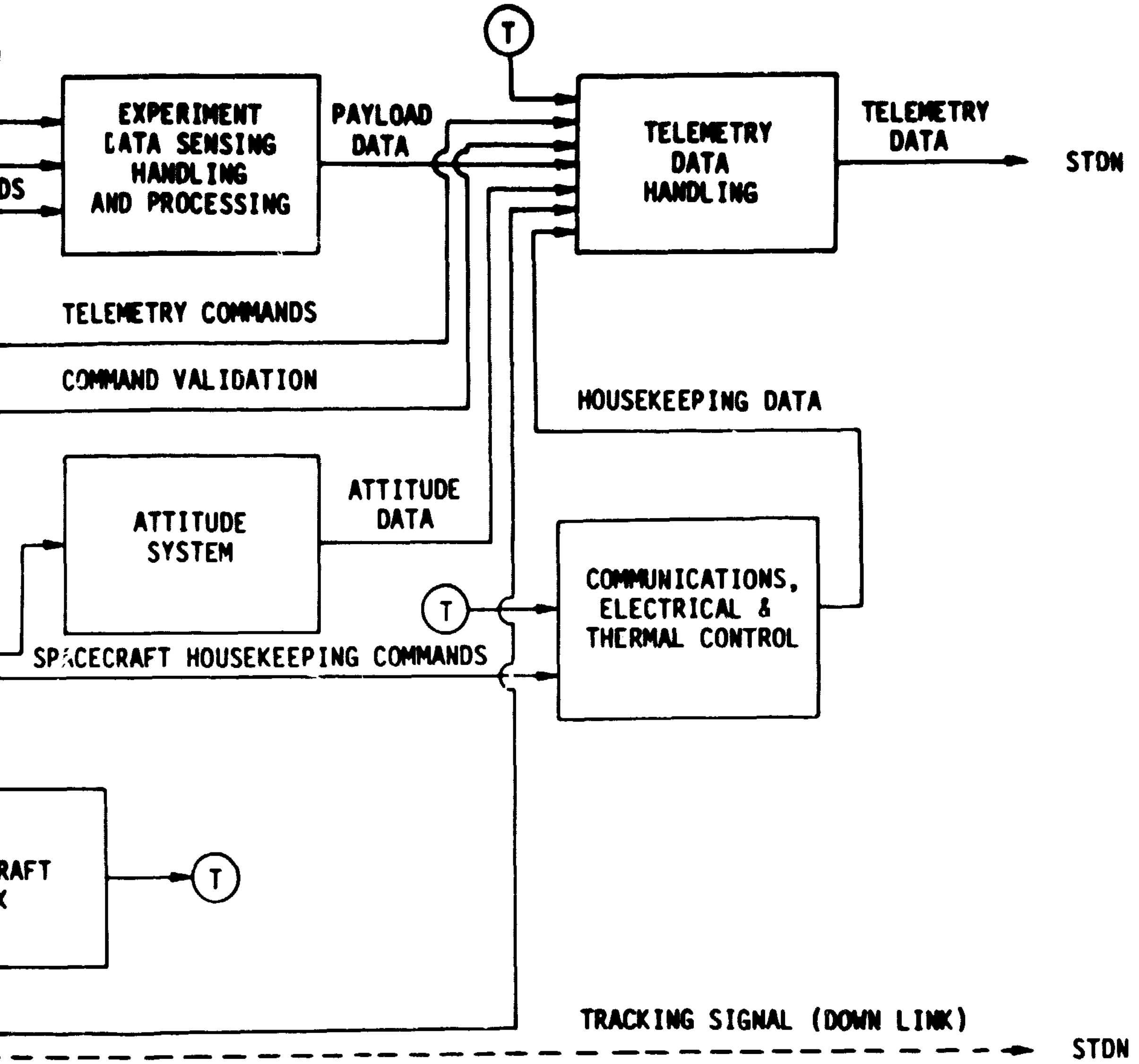

Figure A-1. Satellite Platform

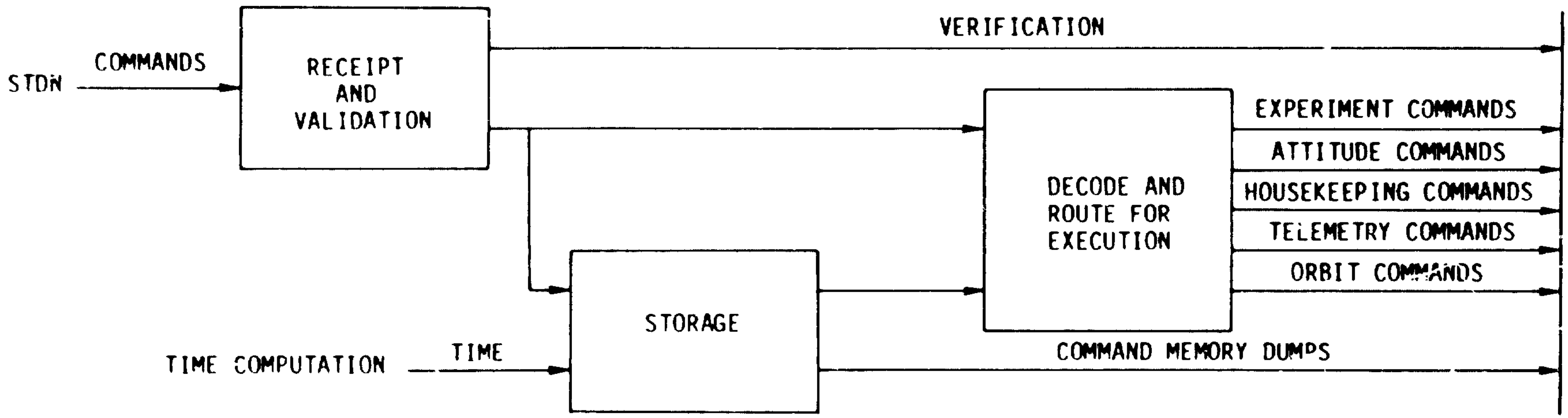

Figure A-2. Command Handling

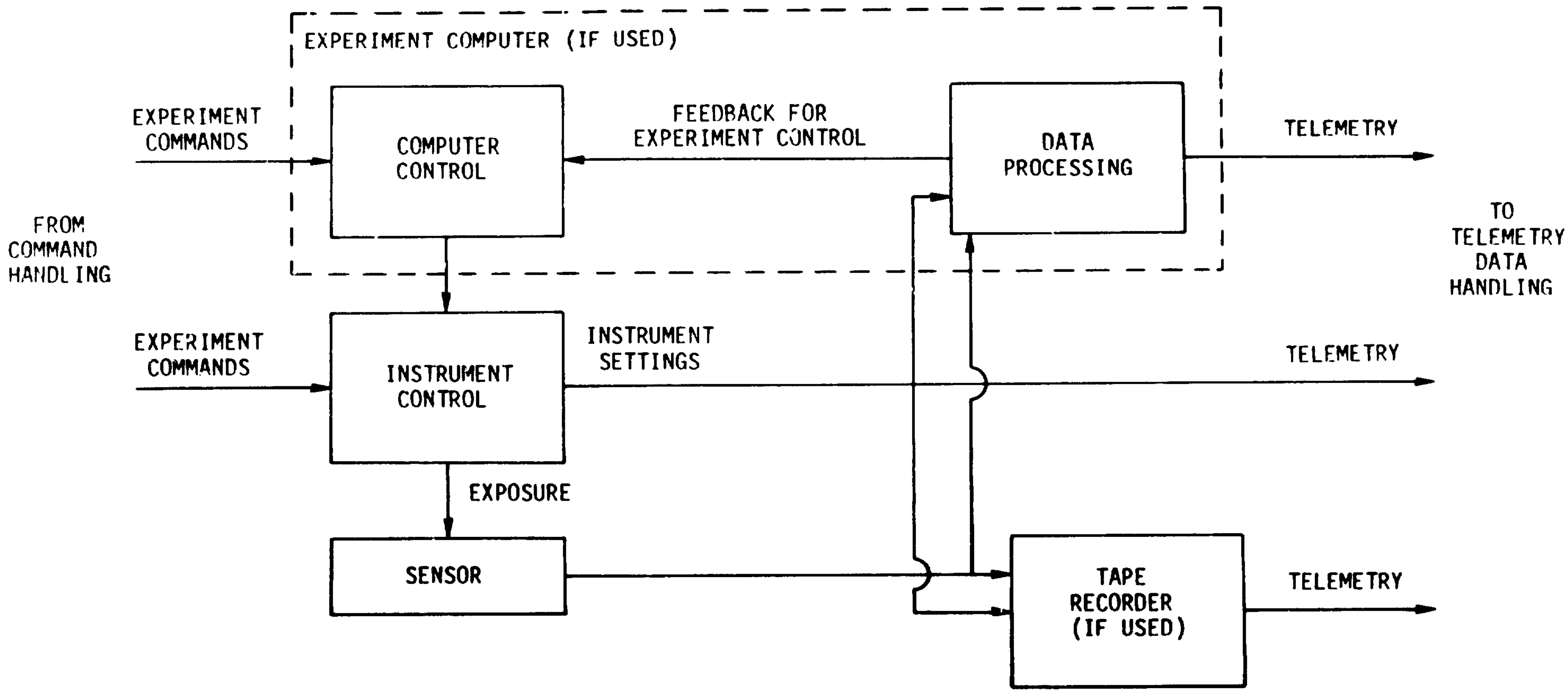

Figure A-3. Experiment Data Sensing, Handling, and Processing

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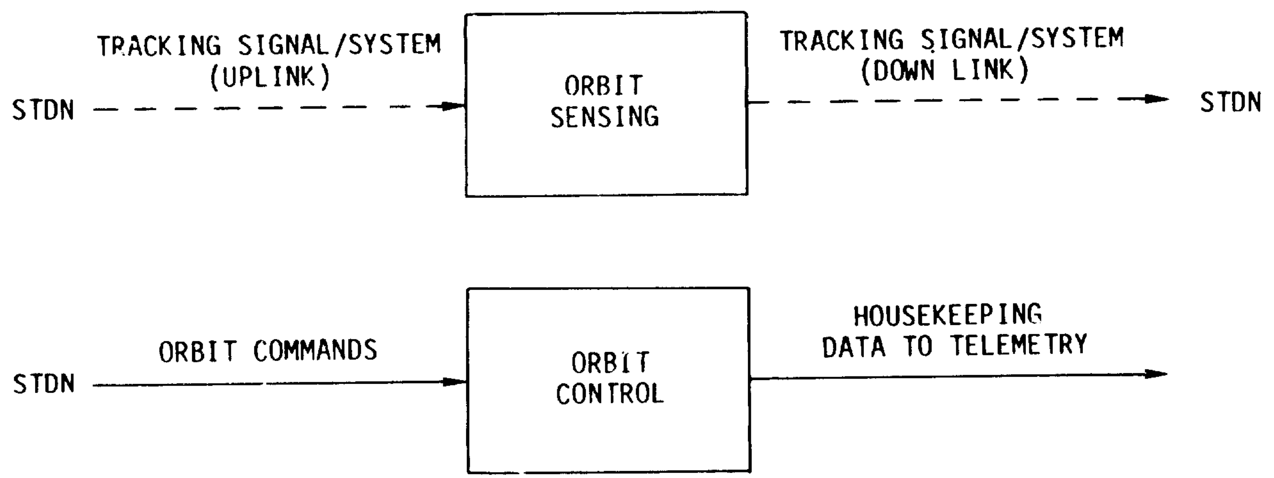


Figure A-4. Orbit System

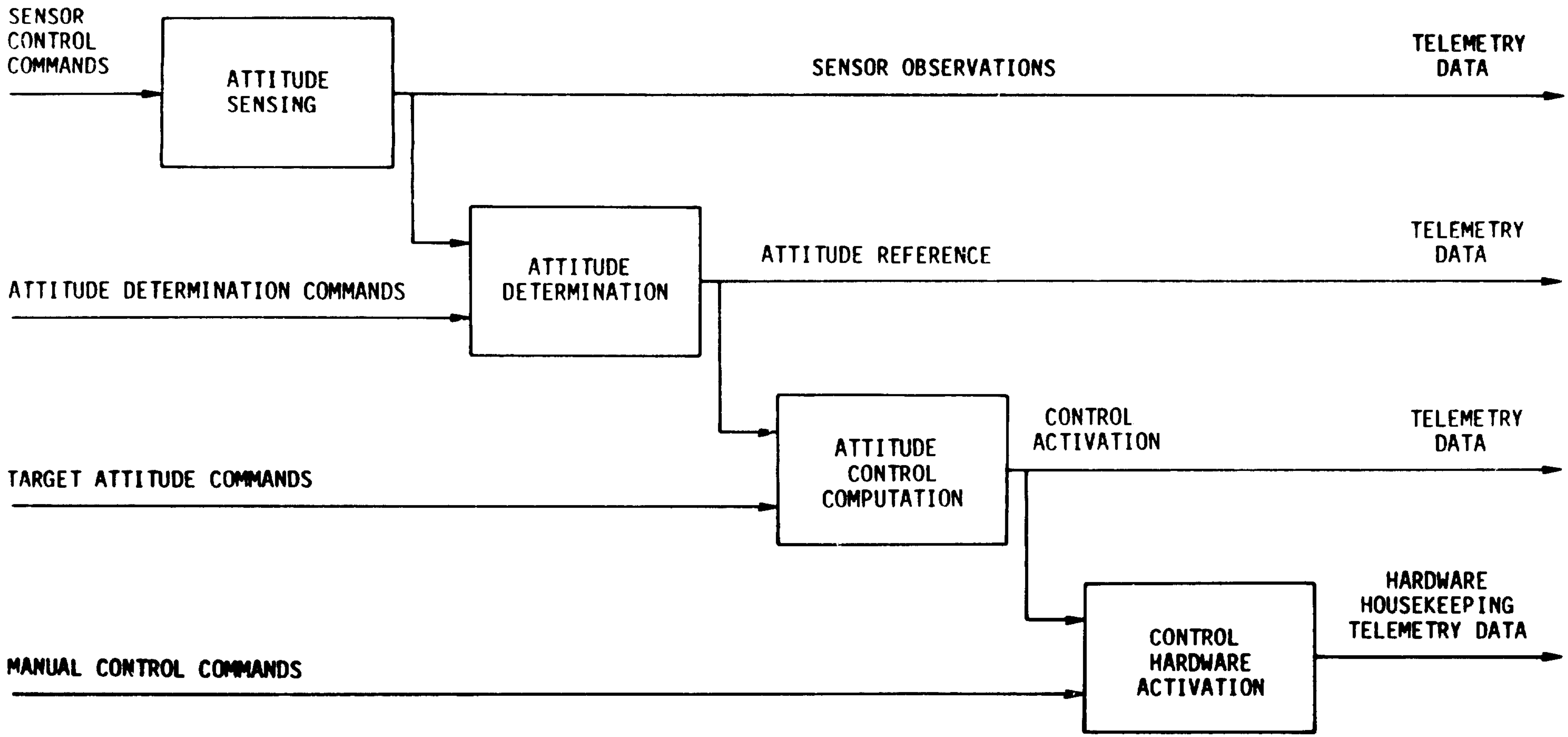


Figure A-5. Attitude Determination and Control

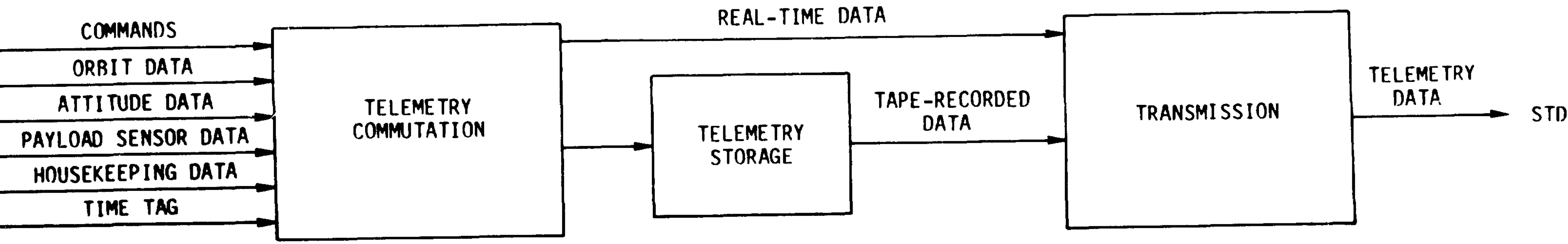


Figure A-6. Telemetry Data Handling

APPENDIX B

MISSION SUPPORT SYSTEM

The Mission Support System, as used in this presentation, accounts for any portion of the NASA data system that is not included in either the spacecraft/experiment platform or the scientist user portions of the system. The generalized system described in this paper is appropriate to current missions. A different set of details and system descriptions would be appropriate for a TDRSS-based communications network and for future STS interfaces. Specific differences associated with unique missions will not be addressed. Some functions contained in this generalized description do not apply to some missions. This generalized description will, however, provide suitable bases for discussion of mission differences. The major functional components accounted for in the Mission Support System are listed below.

Mission Operations Control
Command Management
Network Control and Scheduling
Ground/Ground Communications
Spacecraft/Ground Communications
Data Capture, Editing and Decommutation
Attitude Determination
Orbit Determination
Data Distribution

Mission Operations Control. Payload Operations Control Centers (POCC) are concerned with the day-to-day operation and for the maintenance of the health and safety of the satellites. The activities required vary considerably, depending on the mission and design of the spacecraft.

Inputs to the POCC include the following:

- Telemetry from the spacecraft via NASCOM
- Real-time commands from the mission operations staff
- Stored command loads from command management
- Onboard computer loads from spacecraft memory dumps
- Mission and network requirements for allocation of resources

Outputs from the POCC include the following:

- Real-time commands to the spacecraft via NASCOM
- Processed telemetry to various users and for analysis within the POCC by the staff
- Displays for use within POCCs
- Weekly and daily schedules for handling satellite communications

Control, requests, and schedules that drive the operation control function include the following:

Pass schedule from the mission operations staff, as modified and approved by the Network Operations Control Center

Ad hoc instructions from the mission operations staff

Requests fr experimenters (direct or through the mission operations staff, depending on the satellite and the type of request)

Real-time commands are those commands to be executed by the spacecraft as soon as they are received, as opposed to commands to be stored onboard for later execution. Real-time commands may go directly to the spacecraft (via NASCOM and a STDN station) or may be sent in advance to a ground station to be held for transmission during a subsequent pass of the designated spacecraft. Some missions may have permanent or semipermanent files of commands at ground stations from which appropriate commands can be sent upon direction from the POCC.

Activities performed include the following:

Generating command sequences (calculating the spacecraft commands needed to perform a specified operation).

Setting up command bit patterns. In general, separate parts of the bit pattern are calculated or retrieved from data bases and combined into full commands in response to input mnemonics and other parameters.

Checking for critical commands (identifying commands that could have a disastrous effect if executed under certain conditions).

Transmitting commands (sending them over NASCOM lines to a ground station).

Verifying receipt and execution of commands (checking telemetry to ensure that the commands were received by the spacecraft and the commands produce the expected results).

Command Management. This element provides a method for communicating commands to the spacecraft. Considerations in selecting an uplink schedule include command syntax, power budgeting, sensor pointing, and intervals of high radiation dosage. Commands are converted or transformed from a format designed for recognition and use by personnel to a format designed for transmission over a data link for recognition and use by the spacecraft. In some cases, the command requests may be generated by an experimenter or spacecraft engineer in the spacecraft command language. Commands are combined to form a single command request list and merged into a single time-ordered master request list. This master request list is divided into groups of commands called memory loads. A memory load is the largest number of commands which, according to certain constraints (e.g., size of the onboard memory), can be sent during a station pass. The loads are then transmitted to the appropriate Payload Operations Control Center.

Network Control and Scheduling. The Network Operations Control Center's two main functions are scheduling and operations. The scheduling group receives requests for mission support from the Payload Operations Control Centers and is responsible for maintenance time from ground stations in the STDN network.

Requests are merged under the constraints of resources and priorities to produce a conflict-free schedule that will satisfy to the greatest extent possible user's mission support requirements. Weekly and daily schedules are issued. Schedule updates are also issued to accomodate events that have been added or changed too late to be included in the daily schedule. These changes may occur as a result of situations like spacecraft emergencies, network changes, and priority changes. The schedules explicitly commit STDN and NASCOM resources and implicitly commit resources throughout the system. The operations group makes certain that all parts of the network--ground stations, NASCOM, and the operations control centers--are coordinated so as to support each scheduled event.

Ground/Ground Communications - NASCOM. This element, the NASCOM network, functions as a "data conduit." In this context, NASCOM provides for the timely and dependable ground movement and transfer of data and commands between the spacecraft and mission control/support activities. NASCOM does not provide for any "processing" (transformation) of the data. Instead, it refers to the circuits, switching, and terminal facilities in a global system established and operated by NASA to provide longhaul operational communications support for all NASA projects. The system interconnects such facilities as NASA's foreign and domestic tracking and telemetry acquisition sites, launch areas, and mission and network control centers. NASCOM may connect with science data processing centers, experimenter or principal investigators locations, cooperating agencies of other U.S. or foreign government agencies, and spacecraft contractor's facilities.

The longhaul communications channels are, in most instances, full-period circuits or services obtained by lease from the various domestic and

foreign carriers. These services include a variety of terrestrial cable, microwave relay, submerged cable, and communications satellite relay facilities. The network is a global system with over 2.2 million circuit miles of diversely routed voice, low-speed data (teletype), high-speed data, and wide-band communications channels. It includes switching and technical control facilities linking approximately 100 terminal locations. The network provides all NASA mission control and network control centers with real-time communication access to spacecraft in flight.

The NASCOM Network provides for

Transfer of experiment and science data from ground stations to NASA processing centers.

Transfer of spacecraft commands from control centers to the ground stations.

Transfer of any other official communications between NASA facilities.

Spacecraft/Ground Communications. This element consists of the services associated with the transmission of data to the spacecraft and the receipt of data from the spacecraft. There are currently two major communications systems. The larger and more complex system, the Spaceflight Tracking and Data Network (STDN), is managed from Goddard Space Flight Center (GSFC) and is designed to service near Earth spacecraft. This category includes all Earth-orbiting and lunar spacecraft. Those spacecraft having interplanetary orbit or trajectories are serviced by the Deep Space Network (DSN), a global network of ground stations, operated by the Jet Propulsion Laboratory (JPL).

The Satellite Tracking and Data Network (STDN) includes 14 ground stations. The ground stations receive telemetry from the spacecraft, and

provide tracking for orbit determination. The ground station therefore serves as the primary link between the spacecraft and the project control centers, support activities and experimenters.

Command lists are transmitted (uplinked) through the ground station from the Payload Operation Control Center (POCC) to the spacecraft. Telemetry data are received from the spacecraft and transmitted to processing activities (POCC, experimenters facilities, IPD and/or others) via NASCOM and may consist of experiment data, attitude or orbit determination and control data, or general spacecraft maintenance data. The main driver for ground station activities is the schedule of events received from the NOCC over the NASCOM network. These events include spacecraft passes, playbacks of data stored for future transmissions, retransmissions of previously garbled or lost data, and ground station maintenance periods.

Data Capture, Editing and Decommutation. Information processing of sensor data from the NASA unmanned science and application satellites is largely provided by GSFC's Information Processing Division (IPD). Sensor data to be processed can be classified into two categories depending upon their data rate: high-rate data (e.g., image data) and low-rate data. Accordingly they generally follow one of two major functional paths through IPD: the Image Processing Facility (IPF) and the Telemetry Online Processing System (TELOPS).

The Image Processing Facility performs digital image processing, conversion of data onto high-density tapes and selective preparation of digital and photographic products for the users. The IPD's image processing facility will accept the incoming image data and the definitive orbit and attitude information and perform some or all of the following:

analog-to-digital conversion, data formatting, quality assessment, decompression, radiometric and geometric correction, image framing, and editing and reformatting images in preparation for the final product.

The primary outputs are high-density magnetic tapes and photographic (film) products.

The Telemetry Online Processing System (TELOPS) involves the proper receipt and capture of telemetry data; storage and retrieval of telemetry and other related data, such as orbit and attitude data; and the processing of the data for distribution to the users in the form of digital tapes. The processing includes time analysis, editing, decommutation, ancillary attitude/ephemeris processing, and quick-look processing. The processed data then is placed on magnetic tape for storage and distribution to users. A centralized repository for these data is provided.

Attitude Determination. This element accounts for the process of computing the orientation of a spacecraft relative to an appropriate inertial or other reference frame. Attitude determination is based upon data gathered by several types of sensors on the spacecraft and requires sophisticated data processing procedures.

The four major functional subelements of attitude determination follow:

Attitude Control orients the spacecraft in a specified predetermined direction. This process of command generation, includes the generation of attitude changes (control.) based upon current and desired attitude conditions.

Definitive Attitude Determination is the generation of an accurate attitude history perhaps weeks or months after the fact, as specified by

the definitive requirements. This information will generally be used by the end user in the analysis of experimental data.

Attitude Prediction provides forecast information on the spacecraft orientation by using dynamic models to extrapolate the attitude history.

Real-Time Attitude Determination uses incoming telemetry and orbit (ephemeris) data to compute attitudes within a short period of time after receipt of the data. The computed parameters are normally displayed to allow the operations control center monitoring of spacecraft attitude and the performance of onboard attitude control systems. These computed attitude data are used to develop control commands designed to achieve or maintain a desired attitude.

Orbit Determination. This element accounts for the process of providing trajectory and ephemeris support for spacecraft during launches, orbit maneuvers, and mission operations. Mission support operations include updating periodically (or as required) the orbital elements; generating ephemeris, acquisition, and scheduling data; and providing maneuver commands for orbit corrections.

The two major inputs to the orbit determination and control function are

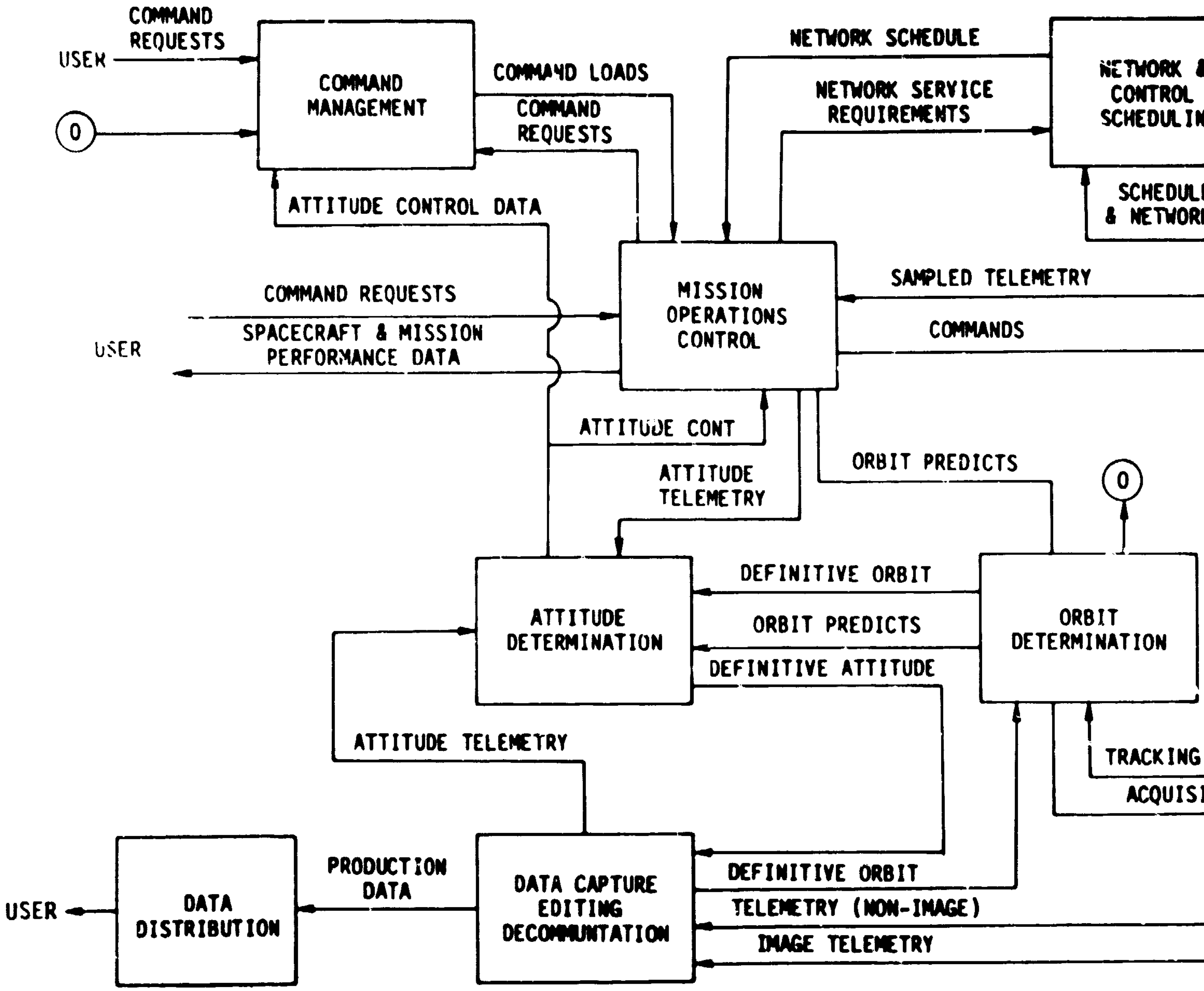
(1) Tracking data from the STDN via NASCOM, and
(2) Ephemeris data (previously generated).

Other inputs include spacecraft conditions, attitude data, and approximate date and time for any maneuvers.

The major outputs are ephemeris data (pairs of times and orbit vectors) and new acquisition data. Other outputs include reports, scheduling and planning data, and maneuver commands.

Data Distribution. This element accounts for the distribution of information and data products to the users. The distribution is done through one of three

major channels. Film products are handled within the image processing facility and delivered directly to the users. Telemetry data products are forwarded to the tape staging and storage facility, where they are packaged and distributed to the users. (This facility can involve NSSDC.)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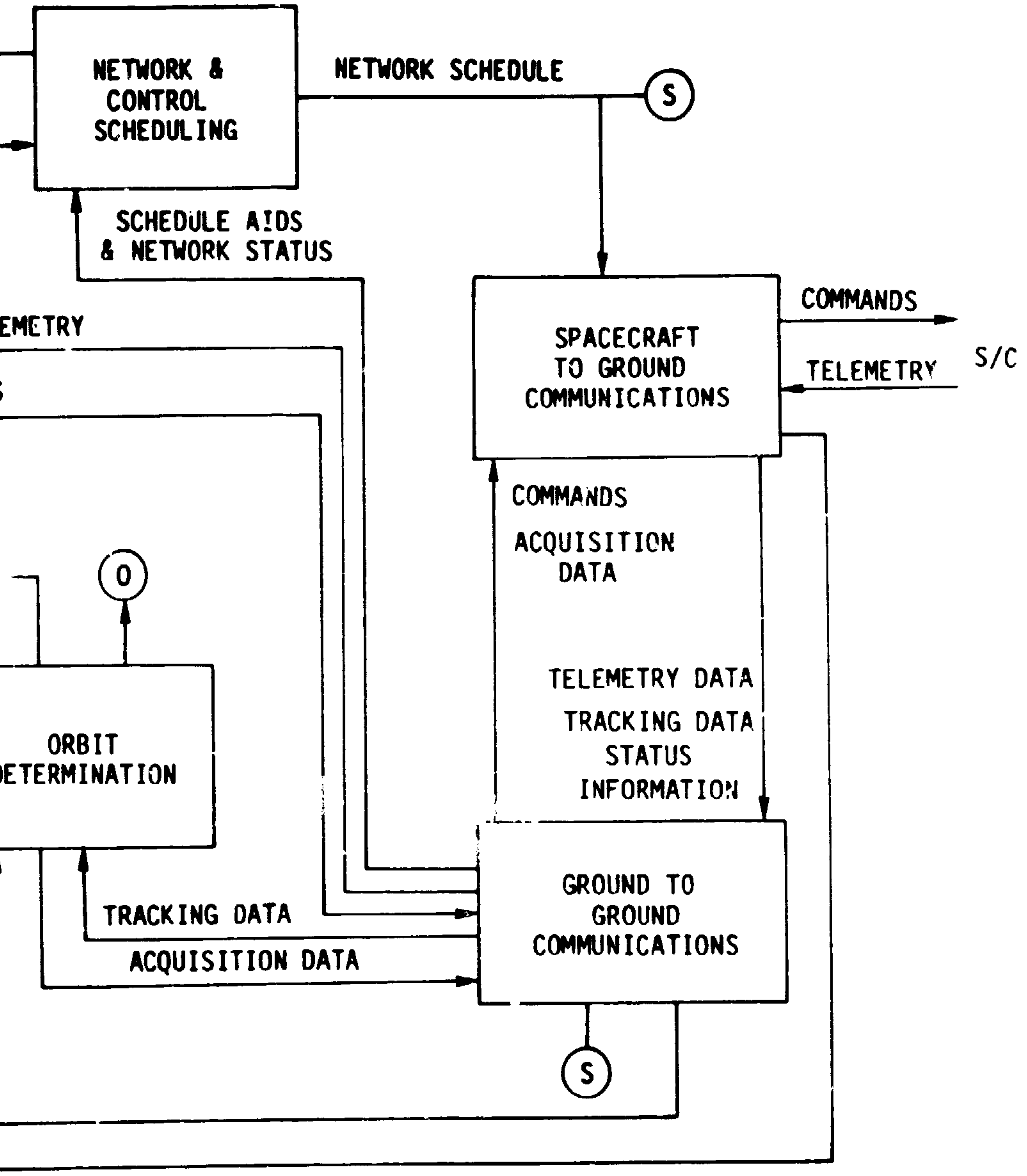

Figure B-1. Mission Support System